DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150687

PROTOTYPE SOLAR HEATING AND COMBINED HEATING AND COOLING SYSTEMS (QUARTERLY REPORT)

Prepared by

General Electric Company
Space Division
Post Office Box 8661
Philadelphia, Pennsylvania 19101

Under Contract NAS8-32092 with

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

(NASA-CR-150687) PROTOTYPE SOLAR HEATING AND COMBINED HEATING AND COOLING SYSTEMS Quarterly Report, Oct. - Dec. 1976 (General Electric Co.) 118 p HC A06/MF A01 CSCL 10A

N78-25538

Unclas
G3/44 21324

U.S. Department of Energy

Solar Energy

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
DOE/NASA CR-150687		
4. TITLE AND SUBTITLE Prototype Solar Heating and Combined Heating and Cooling Systems (Quarterly Report)		5. REPORT DATE January 1, 1977 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS General Electric Company - Space Division P. O. Box 8661 Philadelphia, Pennsylvania 19101		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. NAS8-32092
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 20546		13. TYPE OF REPORT & PERIOD COVERED Contractor Report Oct 76 - Dec 76 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This work was accomplished under the technical management of Mr. William L. Moore, George C. Marshall Space Flight Center, Alabama.

16. ABSTRACT

The General Electric Company is developing eight prototype solar heating and combined heating and cooling systems. This effort includes development, manufacture, test, installation, maintenance, problem resolution, and performance evaluation.

All cost data have been removed from this report.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
	Unclassified-Unlimited William A. Brooksbank, Jr. WILLIAM A. BROOKSBANK, JR. Manager, Solar Heating & Cooling Project Ofc

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	127	NTIS

MSFC - Form 3292 (Rev December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22151

1 JANUARY 1977

QUARTERLY REPORT NO. 2
MONTHLY REPORT NO. 6

SOLAR HEATING AND COOLING SYSTEM DESIGN AND DEVELOPMENT

CONTRACT NAS 8-32092

DATA REQUIREMENT NO. 500-10
DATA REQUIREMENT NO. 500-11

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LIST OF ILLUSTRATIONS

This section has been deleted.

LIST OF TABLES

INTRODUCTION

INTRODUCTION

The Quarterly Status Report (Data Requirements Item No. 500-10) provides a summary of the cost, schedule and technical progress of the program. Since it includes and extends the information included in the Monthly Status Reports (Data Requirements Item No. 500-11) it also meets the contract requirement of a monthly status report. It is supplemented by the financial status report (Data Requirements Item No. 500-27) submitted under separate cover.

The report format is:

Part I - Summary

Part II - Cost

Part III - Schedules

Part IV - Technical Performance

The report is integrated with the program management systems being used on the program, so, where possible, multiple use of program data such as schedules or financial status reports has been accomplished.

PART I

SUMMARY

PART I

SUMMARY

1.1 COST

This paragraph has been deleted.

1.2 SCHEDULE

The working program schedule is posted on the walls of the Program Control Room and is used to monitor program status at "standup" meetings held three times a week early in this period. Daily meetings were held in December. Reviews with GE management are held in the Control Room to take advantage of the detail schedule data base. A summary schedule is shown in Figure 1-1.

Definition of the Operational Test Sites is a schedule problem that became more significant with time. Detail design of the systems is site dependent and it was planned to make the Qualification System similar to one of the prototypes.

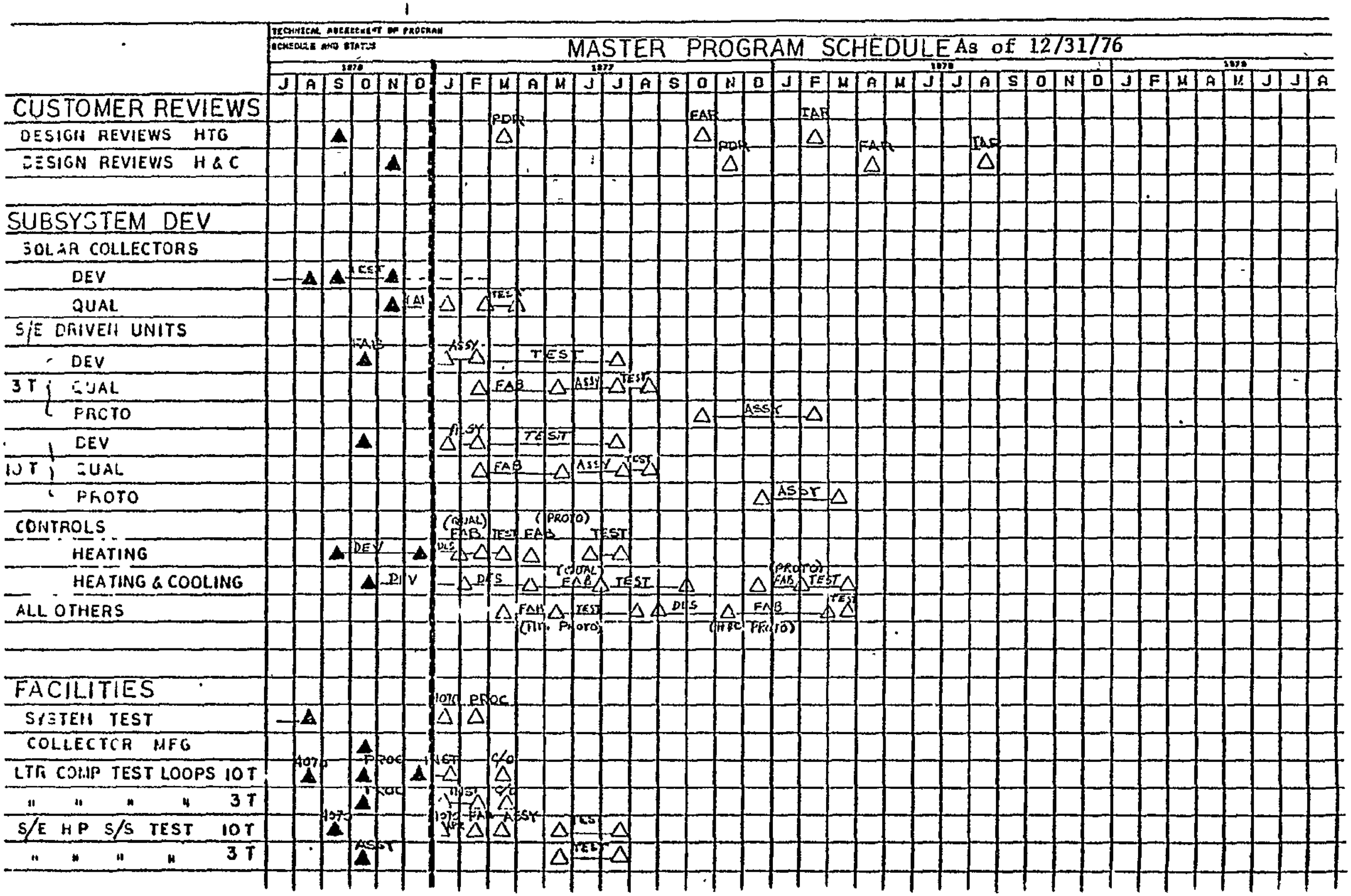

Figure 1-1. Master Program Plan

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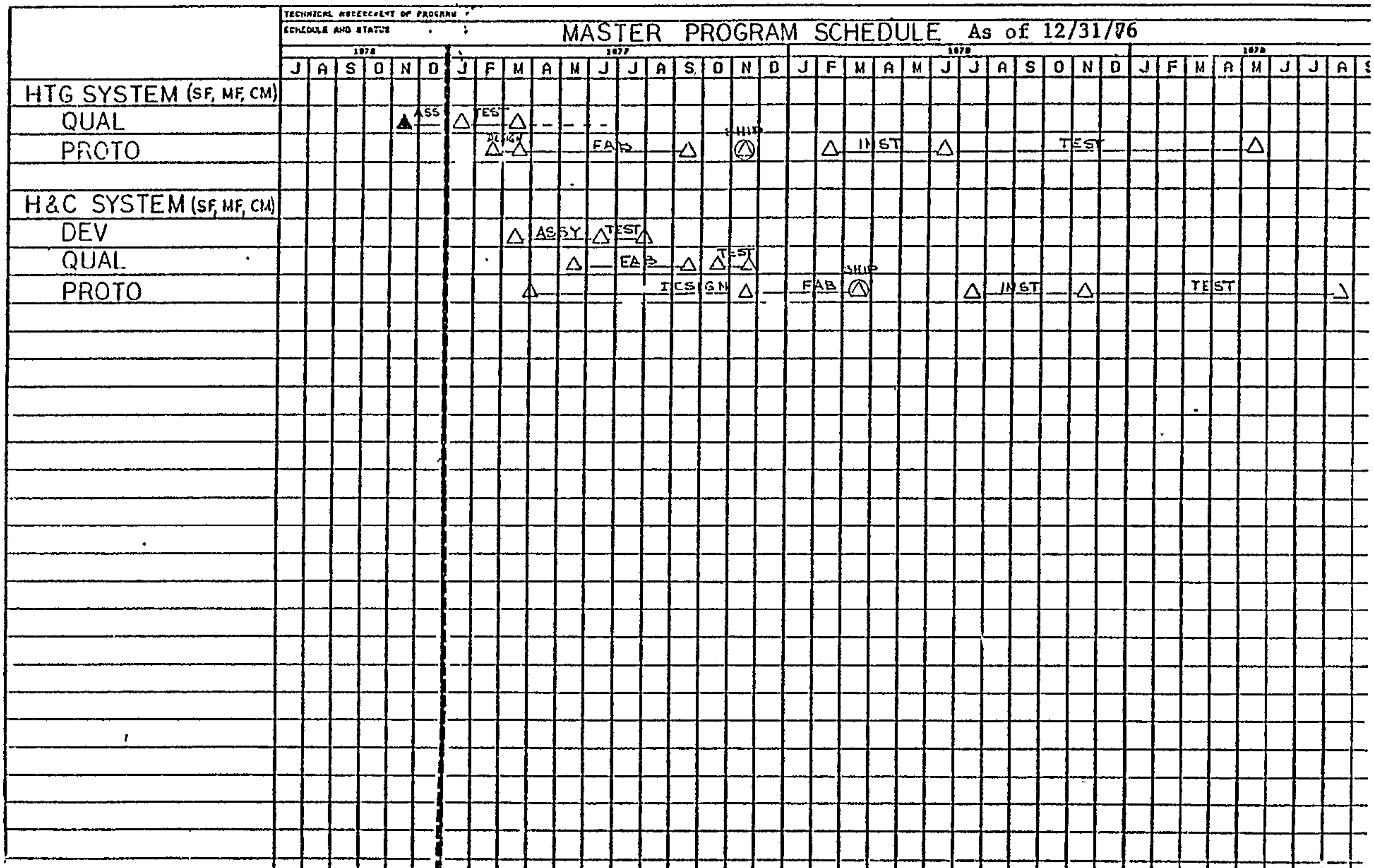

Figure 1-1. Master Program Plan (Cont)

For the heating systems the qualification design is proceeding on the basis of a typical system rather than basing it on one of the prototypes. January 1, 1977 was a critical date with respect to program costs and schedule. The lack of site definition by that date will result in impacts on schedule and/or costs.

1.3 TECHNICAL PERFORMANCE

Program technical status is reflected by the achievement of the key milestones during the period: Heating and Cooling PDR in November and completion of a significant block of development model solar collector testing. Extended tests with the engineering model solar collectors continue.

Highlights of the technical accomplishments and the data summarized in Section IV of this report are as follows:

WBS 1.1.1	Program Direction	Program team increased in key areas of instrumentation and test planning. Presentation to ERDA/NASA on 12/6 on future plans and recommendations..
WBS 1.1.2	Program Control	Updated schedule in Control Room.
WBS 1.1.3	Quality Assurance	Modified Quality Assurance Plan.
WBS 1.2.1	Analysis and Integration	Heating system configuration updated. System building block approach defined. Heating and cooling systems for PDR established and analyzed. Performance goals established for solar cooling. Analysis capability updated.
WBS 1.2.2.1.1 WBS 1.2.2.2.1	Solar Collector Development	Round of engineering model performance tests completed. Qual design released and material ordered. Building installation concepts established.
	"All Others"	Specifications for vendor contacts in various stages of completion.

WBS 1.2.3.1.7 WBS 1.2.3.2.7	Controls	Updated concepts and continued detail designs.
WBS 1.2.3.1.10	System Integration	Detail design for system test and ordering of material.
WBS 1.2.2.2.11	Solar/Electric Driven Heat Pump (Air Conditioner)	Generated analytical performance predictions. Detail design and fabrication of Cycle 1 hardware. Component design and development.
WBS 1.2.3	Test	Solar collector testing. Test facilities fabrication for engine component tests. Planned test facilities for subsystem and system tests.

A key item from the PDR was the recommendation that 3 and 10 ton solar cooling subsystems be developed. This has been the subject of several discussions, presentations and a RID. A key consideration in dropping the 20 ton unit is its limited market potential.

1.4 VARIANCES

Requested variance data is summarized in Table 1-2.

Table 1-2. Program Variances

(From Plan Based on Negotiated Program)

TYPE OF VARIANCE COST	SCHED	PERF	REASON FOR VARIANCE	IMPACT ON TASK	IMPACT ON CONTRACT	CORRECTIVE ACTION
	X		Testing costs are not tracking plan.	1.2.3	None	Testing being scheduled to meet program needs. Cost plan to be revised.
X	X		Lack of operational test sites.	1.2.2.1, 1.3.1, 1.4.1, 1.1	None	Replanning when site data becomes available. Cost/Schedule impact will result.
X			Additional effort in solar collector loop and on cooling subsystem components.	1.2.2	None	Program effort to accommodate revised effort distribution.
X			CR&D Expenditures.	1.2.1	None	Effort not yet needed and/or done at Valley Forge.

PART II

COST

Part II - Cost

This section has been deleted.

PART III

SCHEDULES

PART III

SCHEDULES

Summary Program schedules are shown in Figures 3-1, 3-2, and 3-3. These are extracted from the detailed program working schedules posted in the Control Room at Valley Forge.

Figure 3-1 is a summary key events schedule. It has been revised for this report to provide more program visibility. The principal program key event during this period - the Heating and Cooling System PDR was completed per the schedule. Solar collector development tests were conducted on the facility at Valley Forge with good performance achieved. A qualification design was issued and materials ordered.

Parts for expanders for both the 3 ton and 10 ton solar air conditioning engines are in the final stages of fabrication and assembly of the 10 ton unit is scheduled to start early next period. Other components are in the fabrication process. Engineering tests are being conducted on the air conditioning compressor at Tyler, Texas.

Test facilities for the expanders and other engine components (being constructed with GE funds) are being assembled with the first loop to be completed nearly coincident with the first 10 ton expander. Equipment has been ordered for the solar collector assembly pilot facility.

The schedules for the prototype systems are based on assumed operational test site designation by February 15 for Heating Only and by March 31 for Heating and Cooling. The time available for system design for the Heating Prototype prior to Prototype Design Review is extremely limited and may require a change in the PDR date.

Figure 3-2 is the schedule for the WBS Elements. All scheduled tasks have been started and the major milestone, the H&C PDR achieved.

Figure 3-3 shows the data deliveries. During this period all scheduled items were delivered.

Lack of Operational Test Site Definitions by January 1 continues to cause slip in related events, schedules and costs.

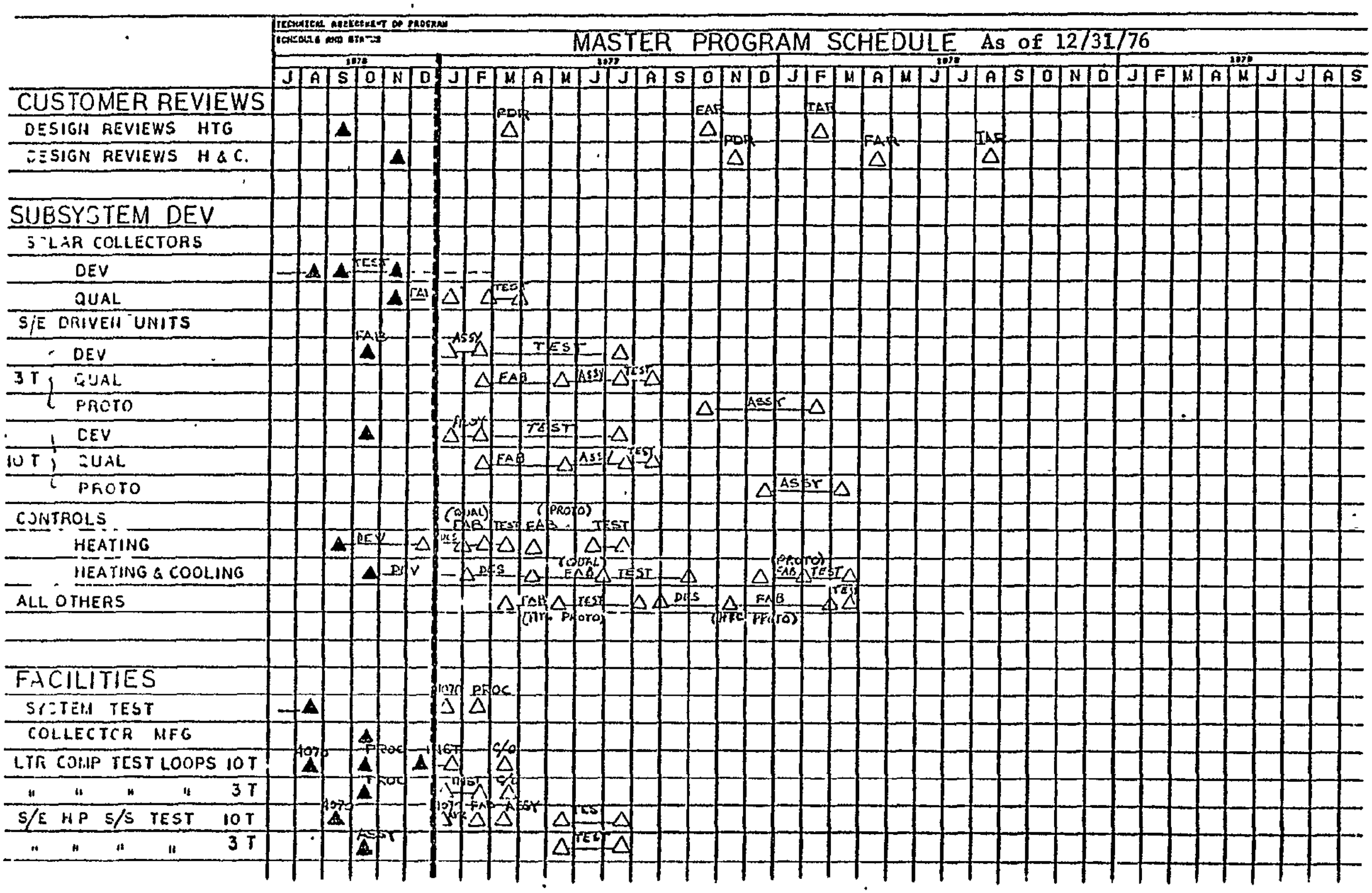

Figure 3-1. Master Program Plan

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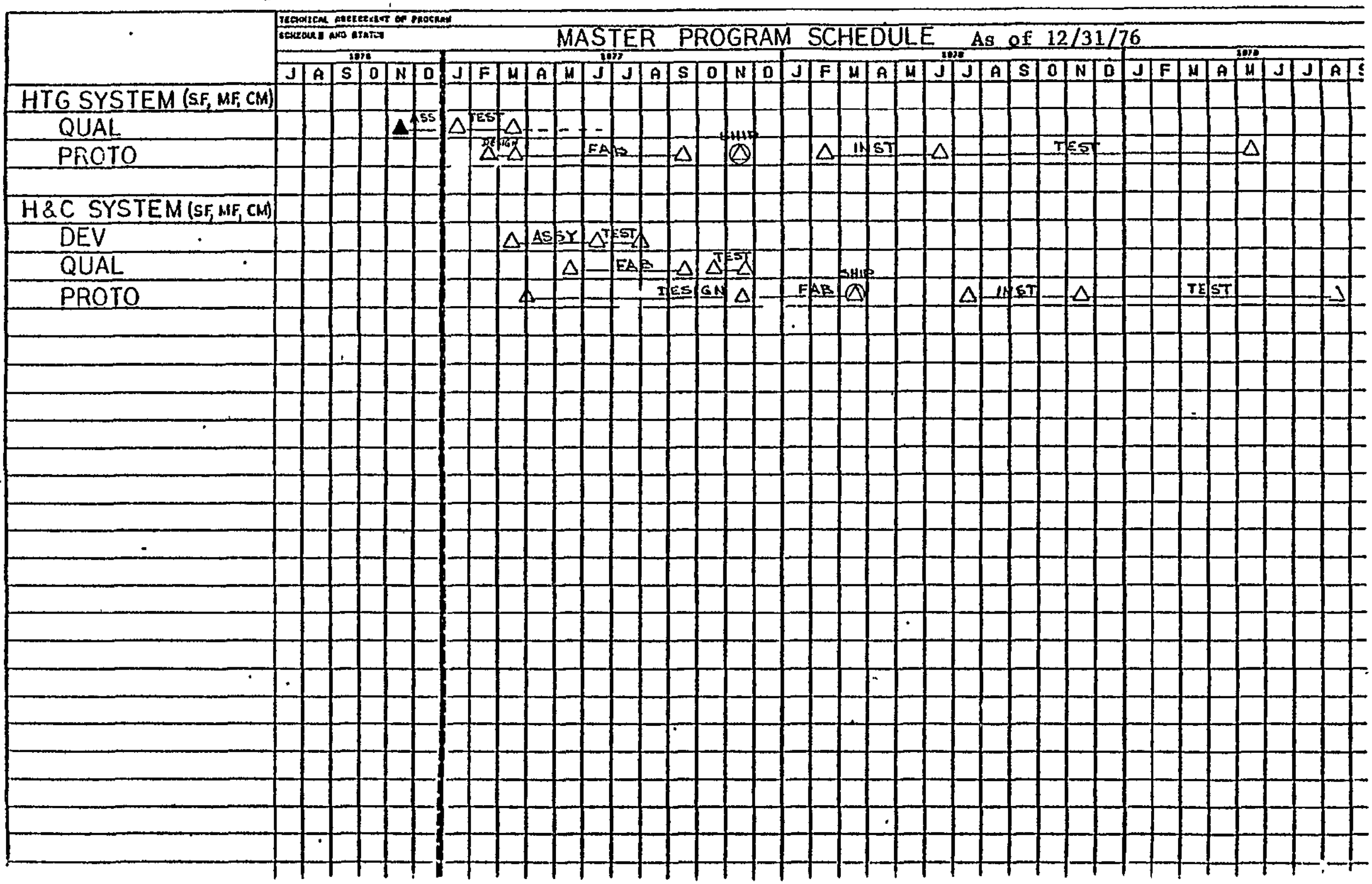


Figure 3-1. ' ster Program Plan (Cont)

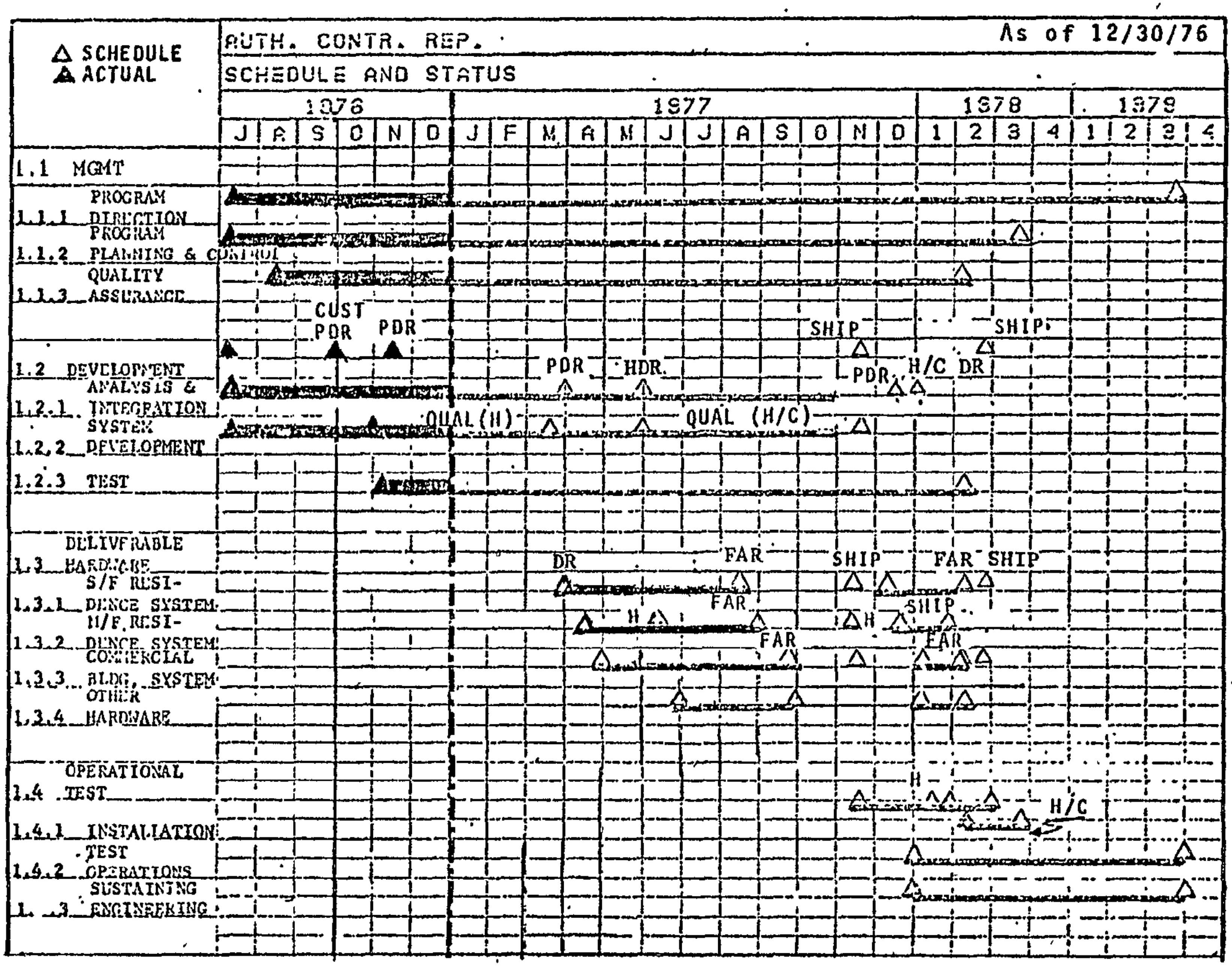
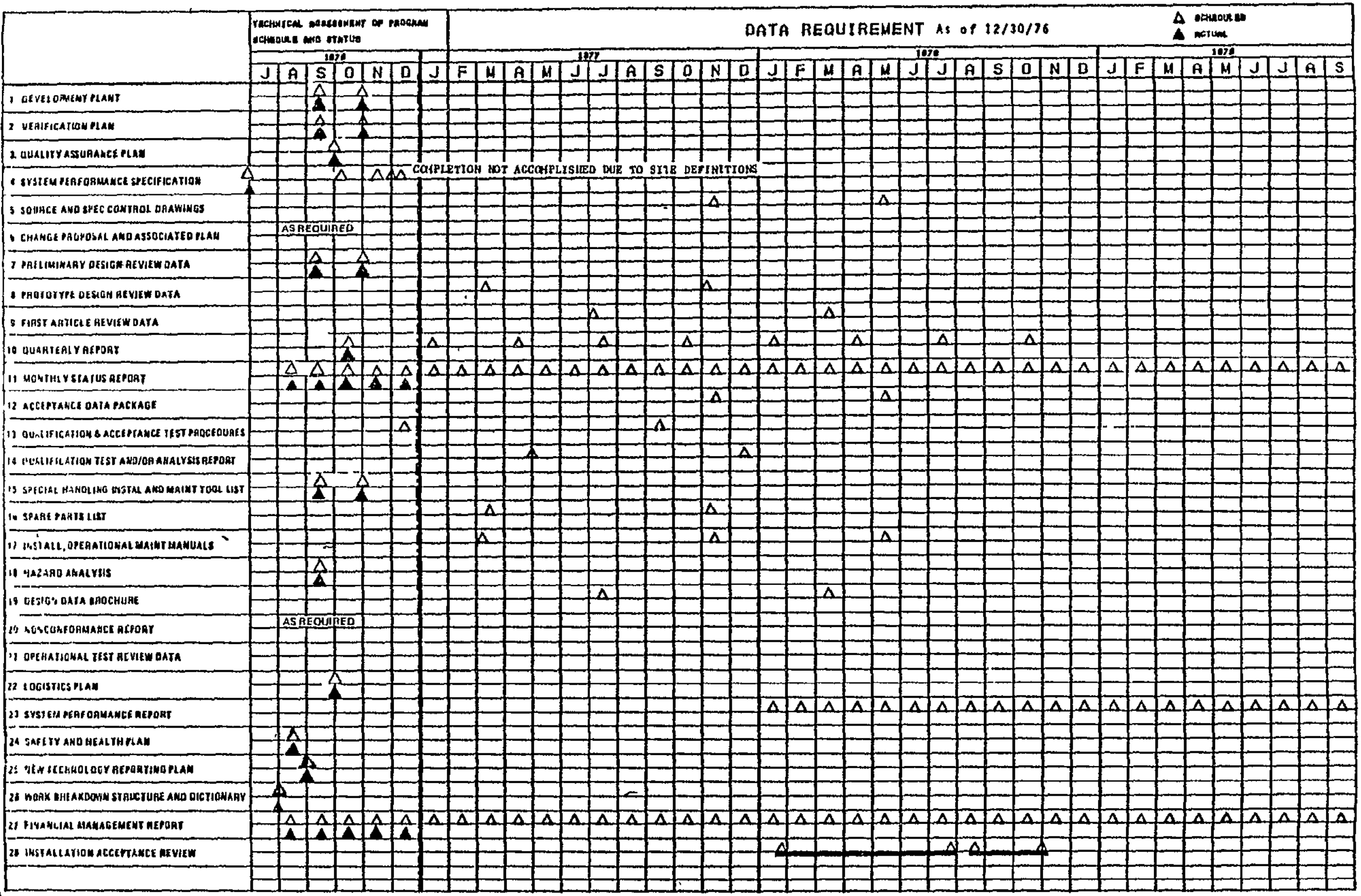


Figure 3-2. WBS Element Schedule and Status



LEGEND. TOP LINE -SCHEDULED COMPLETION
BOTTOM LINE -ACTUAL COMPLETION

Figure 3-3. Data Requirements Status

PART IV

TECHNICAL PERFORMANCE

SECTION 1

TASK 1.1 - MANAGEMENT

1.1 PROGRAM DIRECTION (WBS 1.1.1)

During this period program operation continued in the manner established during the initial quarter. The program team, shown in Figure 1.1-1, is essentially the same as that established during the initial quarter. Minor changes have been made and are shown in this figure. A few additional people were added to this team, primarily in the test area to increase the capability for instrumentation design and systems planning.

Major customer coordination events included a meeting at Huntsville on October 14. This meeting was a follow-up to the heating only preliminary design review and involved the discussion of key items raised at the PDR. Among these items was the approach of using utilities for the distribution of solar heating equipment, at least in the early stages of commercialization. There was also considerable discussion on the sizing of systems with respect to the amount of energy provided by the solar portion of the system. Several criteria can be used to establish the size of the system and the one used for the PDR examples, cost of energy delivered, tends to result in relatively small percentage contributions by the solar portion of the system. It is to be emphasized that the system designs developed on this program by General Electric can accommodate a wide range of sizes which results in similarly wide ranges in the percentage contributions by the solar portion of the system. Percentage contribution of the solar system will be a factor in sizing the prototype system.

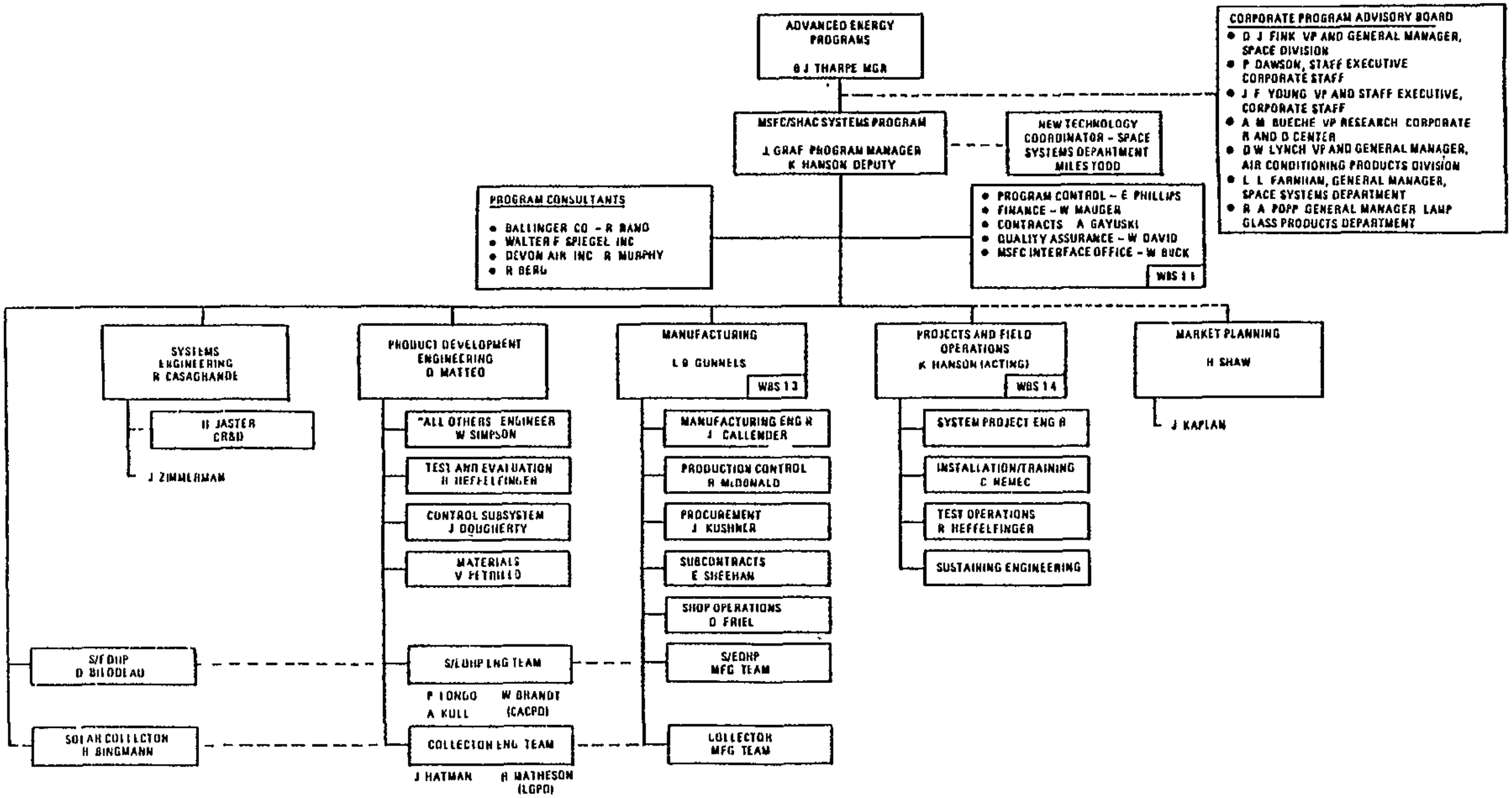


Figure 1.1-1. Program Organization

The heating and cooling preliminary design review was held on November 17. It also produced topics which have resulted in additional discussion with NASA. A principal topic of interest is the selection of sizes of the solar/electric driven cooling equipment to be developed on the program. NASA has requested additional justification of the recommendation to develop two sizes of solar powered cooling equipment, 3 ton and 10 ton. Discussions are continuing in this area.

A third primary event involved a NASA requested presentation at ERDA headquarters on December 6. A list of topics requested to be treated was provided and material reviewed in a meeting in Huntsville on December 1. Included in the GE presentation was information on the recommendation to develop three and 10 ton solar driven cooling subsystems. Late in this report period a series of questions was received from NASA as a part of the follow-up to the December 6 meeting.

Internal General Electric meetings during this period included a program review and integration meeting attended by the program team on October 27, 1976. The material collected and discussed at this meeting was used in the heating and cooling PDR. Management reviews included a PAR meeting on November 1 and a regular monthly management review on December 9. A special internal GE meeting of interest was a corporate collector design review. This review, held for the purpose of obtaining an outside independent assessment of the collector design, was held on December 9. NASA has requested a copy of the review team's comments from this meeting.

The program is proceeding without designation of the operational test sites.

The implications of this have been separately discussed with NASA and included in the monthly progress reports. One of the consequences is that planning for the system qualification testing for the heating only system is proceeding on a general basis and will not be related to any particular test site as was originally intended. The contracts organization of General Electric has been requested to formally notify the MSFC contract operations of the consequences of the lack of operational test site designation.

1.2 PROGRAM PLANNING & CONTROL (WBS 1.1.2)

1.2.1 PROGRAM CONTROL

The program approach was updated in a development plan and a verification plan which were prepared and submitted as part of the heating and cooling PDR package. These plans are extensions of the plans originally submitted with the proposal and represent updatings to reflect current program approaches.

The basic program control tool being used on this program is the control room. It was used during this period to schedule key milestones and program activities and monitor their status. This control room represents the official program schedule against which GE's technical status and progress is monitored. The schedule data required for the monthly, quarterly and management reports is extracted from the control room posting. The schedules in the control room include an overall program summary and with detailed task schedules on the side walls. The individual task sections of the control room schedules are monitored and maintained by the responsible task leaders. In December daily program status meetings were initiated to more closely follow hardware items.

Previously meetings were held 3 times per week. Problems involving interactions are identified and resolved at these meetings by the assignment of action items which are posted and monitored in the control room.

A major update of the control room schedules was initiated in mid-December. This exercise, known as "roll the walls", involves an update of the detailed task schedules which cover six month periods. The initial posting of these schedules, done early in the program, was nearly 6 months old and needed to be extended. One area of the schedule which had to be adjusted involved design of the prototype system for the operational test sites. Original schedules had been based on identification of these sites at the PDR meeting. Currently the assumption is that the heating only sites will be identified by February 15 with the heating and cooling sites identified by March 1.

In the budgets area the program was monitored on the basis of the profile presented in the last quarterly report. Overall budget results are posted in the control room and available on a continuing basis for inspection by management. A cost review exercise is currently underway with results to be presented in the next quarterly report.

1.2.2 DATA MANAGEMENT

The scheduled data submittals completed during this period were as follows:

Data Requirements No.

-1 Development Plan (Update in PDR Data Pkg.)

-2 Verification Plan (Update in PDR Data Pkg.)

-4 System Performance Specification
(Updated, Preliminary for PDR Data Pkg.)

-7 PDR Data Package (Heating & Cooling)

-11 Monthly Status Reports (2)

-15 Special Handling, Installation, and Maintenance Tools
(Update for PDR Data Pkg.)

-18 Hazards Analyses (Updated for PDR Data Pkg.)

-24 Safety and Health Plan (Change 1)

-26 Financial Management Report (2)

Comments were received on the previously submitted Quality Assurance Plan revision and it is being updated to reflect these changes.

Minutes for the Preliminary Design Review held on November 17 were submitted including the then completed RIDs. At the date of this report, 3 RID's are still outstanding from this PDR.

1.2.3 CHANGE CONTROL

The status of Change Proposals is as follows:

CP-001 Submitted First Quarter - has been discussed with NASA - Awaiting action

CP-002 Cancelled - NASA acted on an informal submittal and incorporated the content of CP-002 in Modification No. 1

The status of Contract Modifications is as follows:

Modification No. 1 - Executed (No cost impact)

Modification No. 2 - Reviewed by GE and awaiting final action (No cost impact).

1.3 QUALITY ASSURANCE (WBS 1.1.3)

Revision A of the Quality Assurance Plan (dated 9/30/76) was released during this period. Comments from NASA on the system for reporting non-conformances are being incorporated into the Plan. A non-conformance reporting form is being created that meets contract requirements. A new form was created instead of using the existing non-conformance report in the GE-VF quality system because the existing form is used for aerospace hardware and is subject to a disciplined set of working procedures. The Quality Assurance Plan for this program calls out slightly different procedures and it was considered appropriate to avoid the complexity associated with using the same form in two sets of working procedures.

Significant Quality Assurance activities this period were:

1. Development of a non-destructive method of measuring collector tube wall thickness in the area of tube enclosure. Method developed utilizes a standard comparator and enables wall thickness to be measured within $\pm$ 0.001 inch for entire curvature of enclosure.
2. Maintenance of development hardware configurations for evaluation of performance and wear results. This includes detail measurements of significant dimensions as well as discrepancies.

SECTION 2

TASK 1.2 - SYSTEM DEVELOPMENT

2.1 INTRODUCTION

The major program activity this period was in the heating and cooling system definition and in the S/EDHP design. Additional development activity was started on the Heating only system hardware definition. Key results of these activities are presented in this section, organized by WBS elements.

2.2 ANALYSIS AND INTEGRATION (WBS 1.2.1)

Systems analyses activities were directed toward identifying and verifying the "best" system configurations for the heating and cooling systems and to develop the parameters for the heating system configurations building blocks.

The heating and cooling system studies were performed using the Washington D.C. area as one baseline climate region, selected on the basis of climate and demographics. System configurations and parameters were evaluated for the Fort Worth, Texas climate region as well to introduce a longer, more severe cooling season and different climate factors to support the selection of the heating and cooling system building block sizes.

The approach of assuming building models, establishing configurations, conducting trade studies and selecting baseline configurations was followed for the heating and cooling systems definition similarily to the procedure established for the heating only systems.

Preliminary system specifications were written using the study models to form a basis of design for the Operational Test sites.

The order of presentation of the systems material is as follows:

1. Baseline Systems Configurations (Heating Only System)

2. Analysis of Heating and Cooling Systems

3. System Trade Studies

2.2.1 BASELINE SYSTEM CONFIGURATIONS (HEATING ONLY)

2.2.1.1 System Modifications

There have been several changes in the system configurations and new system schematics are presented in Figures 2.2-1 through 2.2-3. These include the following:

1. In the HSF system the solar direct mode of energy distribution has been replaced by the solar indirect mode. This change greatly simplifies the control logic for the storage and distribution functions at practically no penalty (less than 2%) in the system performance. Now, instead of a combined storage and distribution loop, there is a separate loop for each of these functions, resulting in the replacement of two control valves with a pump.

2. In the HMF and HCOM systems the implied hydronic coil bypass is now explicitly shown.

2.2.1.2 System Building Blocks

A building block concept has been developed to identify system component characteristics associated with solar energy systems for applications which span the range of single and multi-family residences through commercial buildings. The component characteristics were defined by system analysis for the baseline systems for each generic application. For larger or smaller sized systems the component characteristics were scaled from the baseline values. The component characteristics

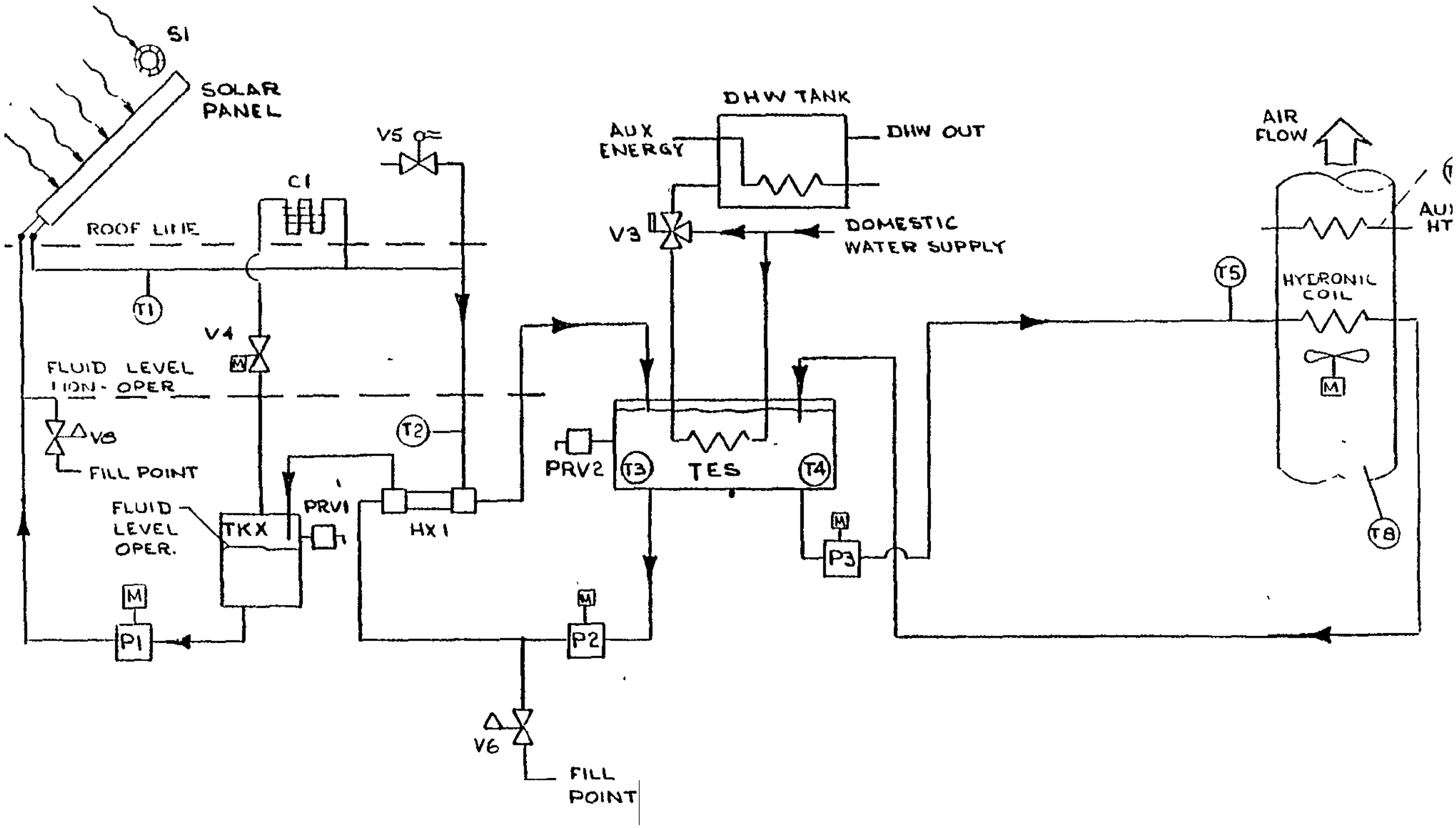


Figure 2.2-1. System Schematic, Heating Single Family

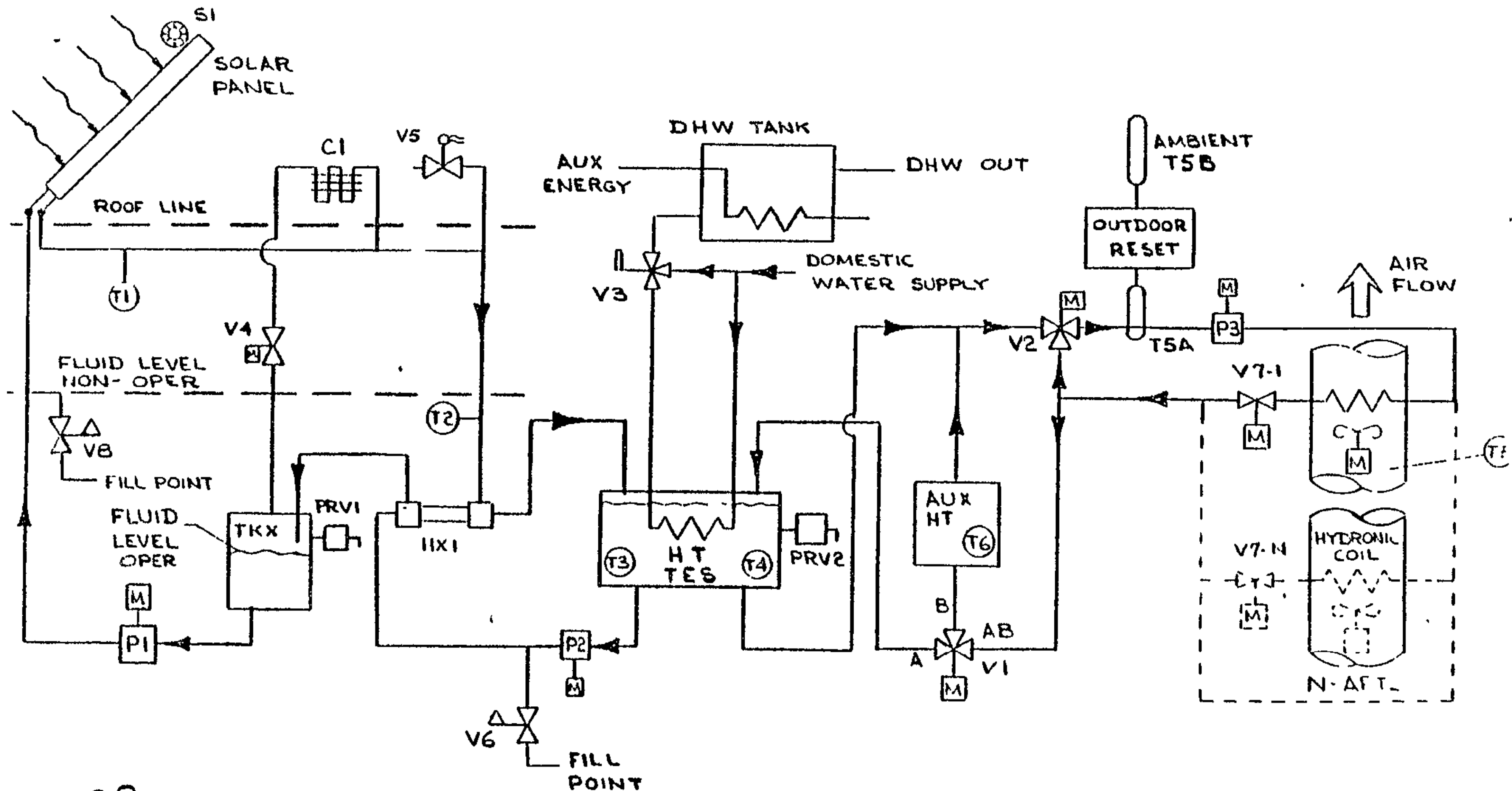


Figure 2.2-2. System Schematic, Heating Multi-Family

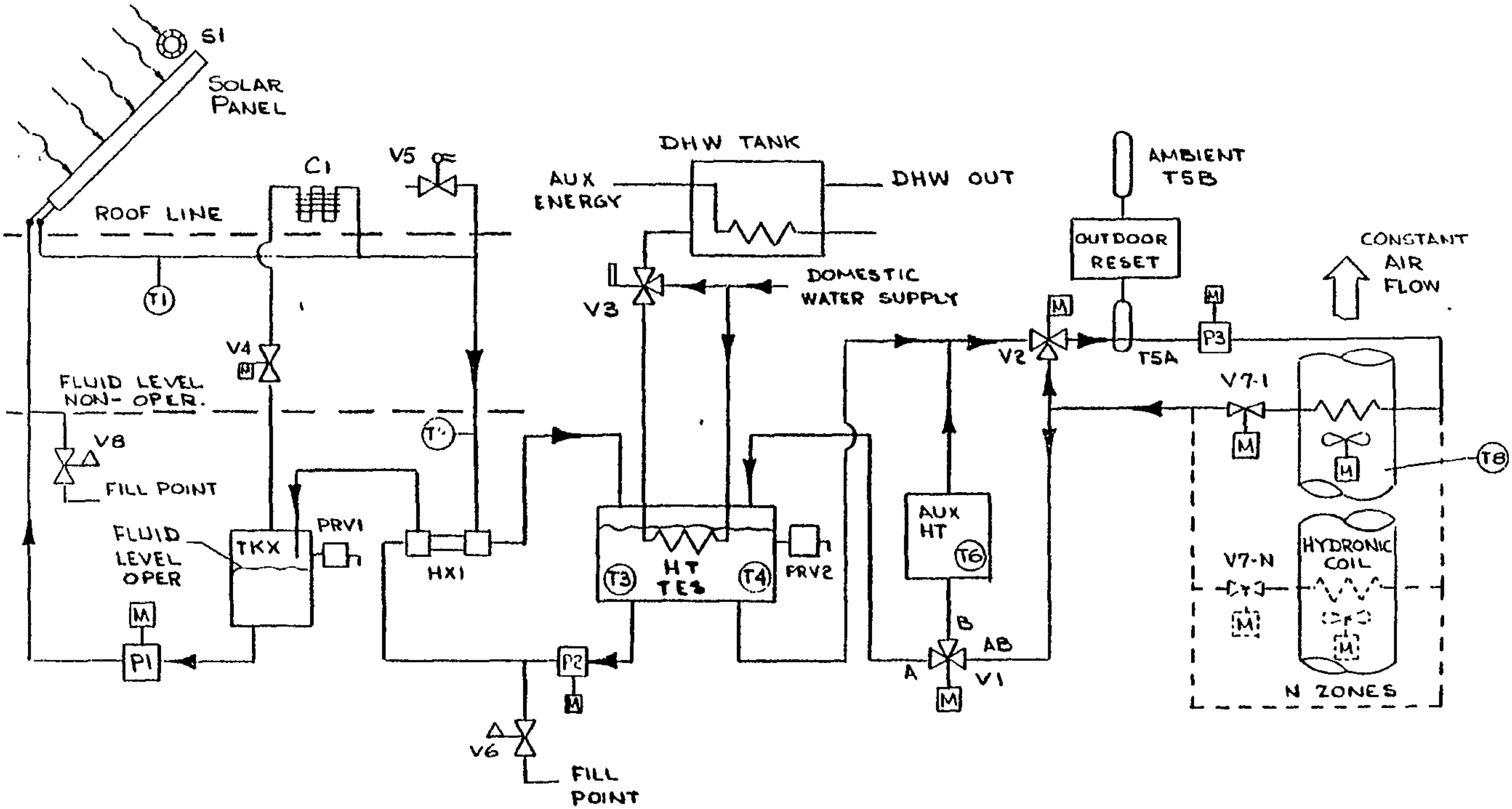


Figure 2.2-3. System Schematic, Heating Commercial

as well as the space and domestic hot water loads for five building blocks within each building category are defined in Table 2.2-1.

2.2.2 SYSTEMS ANALYSIS OF HEATING AND COOLING SYSTEMS

The heating and cooling systems were identified for the single family (SF), multi-family (MF), and commercial (COMM) building categories.

The heating and cooling loads were obtained using the building characteristics defined for the heating only system which exceed or meet the ASHRAE 90-75 instruction standards. Tradeoff studies were performed using 1964 Washington, D.C. and 1962 Fort Worth, Texas weather conditions. Washington, D.C. provides a case for which the cooling load is smaller than the heating load while Fort Worth exhibits a larger cooling than heating requirement. Due to the population concentration and high fuel costs of the Washington area, it becomes a more important region for SHAC systems applications.

2.2.2.1 Baseline Configurations

The baseline systems for each building type are presented in schematic form in Figures 2.2-4 through 2.2-6. The heating portion of the systems is identical to the heating only systems.

The peak and annual energy requirements of the three building types at both locations are presented in Table 2.2-2. The baseline collector configuration for each building and location, obtained through economic considerations are given in Tables 2.2-3 through 2.2-5. The baseline systems will supply 68, 67, and 58 percent to the total energy requirements of the SF, MF, and COMM buildings respectively for Washington, D.C. and 69, 72, and 78 percent of the respective Fort Worth buildings total energy requirements. The monthly system performance obtained using the baseline collector configurations for both locales are presented in

Table 2.2-1. System Building Block Characteristics

	PARAMETER	UNITS	SYSTEM BLDG BLOCKS					NOTES[1]
	BLOCK DESIGNATION	–	A	B	C	D	E	
1	SPACE HTG. LOAD	BTUY	78×10^6	117×10^6	157×10^6	209×10^6	261×10^6	
2	PEAK HTG. DEMAND	BTUH	38×10^3	57×10^3	76×10^3	102×10^3	127×10^3	
3	DHW HTG LOAD	BTUY	20.3×10^6	→				@90F ΔT
4	PEAK DHW HTG DEMAND	BTUH	41×10^3	→				@ΔT 105-37
5	DHW FLOW RATE	gpm	1.2 Max	→				
6								
7	DHW SOURCE WATER TEMP	F	37	→				MINIMUM
8	HEATED SPACE TEMP	F	72	→				
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

1 LOADS AND EQUIPMENT SCALED FROM PDR MADISON WI. RESULTS.

Table 2.2-1. System Building Block Characteristics (continued)

COLLECTOR LOOP

	PARAMETER	UNITS	SYSTEM BLDG BLOCKS					NOTES
	BLOCK DESIGNATION	-	A	B	C	D	E	
1	COLLECTOR MODULES	EA	12	18	24	32	40	
2	" AREA	FT²	178	267	356	475	593	EFFECTIVE
3	LOOP FLUID	-	35 - 50% PRESTONE II / WATER					
4	FLUID RATE	gpm	2.6	4.0	5.3	7.0	8.8	@.22 GPM/COL
5	OUTLET TEMP. TI	F	290° MAX		→			
6	LOOP FLUID VOLUME	gal	TBD	→				@60°F, New Fill
7	OUTLET PRESSURE	PSIG	TBD	→				@260°F
8	ΔT HT. EXCH.	F	32	→				COLLECTOR FLUID
9	HT. EXCH. HEAT RATE	BTUH	38×10^3	56×10^3	75×10^3	100×10^3	125×10^3	
10	EXP TANK VOLUME	gal	TBD	→				
11	" " PRESSURE	PSIG	TBD	→				
12	PUMP FRICTION HD.	FT	50	→				
13								
14								
15								
16								
17								
18								
19								
20								

Table 2.2-1. System Building Block Characteristics (continued)

DISTRIBUTION LOOP

	PARAMETER	UNITS	SYSTEM BLDG BLOCKS					NOTES"
	BLOCK DESIGNATION	–	A	B	C	D	E	
1	FLUID		WATER					
2	FLOW RATE	G.P.M	7.8	12.0	15.9	21.0	26.4	
3	PUMP FRICTION HEAD	FT.	6					
4								
5								
6	HYDRONIC COIL HTG RATE	BTUH	28×10^3	42×10^3	55×10^3	74×10^3	92×10^3	
7	" " ΔT	°F	23					AIR SIDE
8								
9	AIR FLOW RATE	SCFM	1200	1800	2400	3200	4000	
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

Table 2.2-1. System Building Block Characteristics (continued)

STORAGE LOOP

	PARAMETER	UNITS	SYSTEM BLDG BLOCKS					NOTES
	BLOCK DESIGNATION	–	A	B	C	D	E	.
1	LOOP FLUID	–	WATER →					
2	FLOW RATE	gpm	7.8	12.0	15.9	21.0	26.4	
3	LOOP FLUID VOLUME	gal	178	267	356	475	593	PLUS LINE FILL
4	ENERGY STORAGE VOL	gal	178	267	356	475	593	1.0 gal / Ft^2
5	TES TANK VOLUME	gal	TBD →					
6	" " TEMP. T4	F	250 MAX →					
7	" " PRESS.	PSIG	15 MAX →					
8	" " HEAT LOSS	BTUH	TBD →					
9	PUMP FRICTION HEAD	FT	6 →					
10	DHW. HT. EXCH. HT RATE	BTUH	TBD →					@ 1.2 gpm
11	" " " ΔT	F	(140-50)=90					AVG.
12								
13								
14								
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16								
17								
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19								
20								

Figures 2.2-7 through 2.2-12. For all cases energy deficits exist during peak heating and cooling months. While during the off-peak months nearly all the energy required by the buildings is supplied by the appropriate solar system.

Table 2.2-2 Building Energy Requirements

	Peak Heating (KBTU)	Peak Cooling (KBTU)	Annual Heating (MMBTU)	Annual Cooling (MMBTU)	Annual DHW (MMBTU)
Single Family					
Washington	36	35	56	16	20
Fort Worth	28.8	40.6	23.4	41	16
Multi-Family					
Washington	218	171	291	106	180
Fort Worth	189	205	119	282	131
Commercial					
Washington	1371	1126	1317	650	70
Fort Worth	1032	1379	596	1848	44

Table 2.2-3. System Description - HCSF Baseline

MAJOR SOLAR HARDWARE	FORT WORTH	WASHINGTON, D.C.
SOLAR COLLECTOR AREA	267 FT^2 (18 TC-100 PANELS) $280^{o}F$ MAX. OPERATING TEMPERATURE	326 FT^2 (22 TC-100 PANELS) $280^{o}F$ MAX. OPERATING TEMPERATURE
THERMAL ENERGY STORAGE	400 GAL. OF WATER $95^{o}F$ MIN. TEMPERATURE $250^{o}F$ MAX. TEMPERATURE	490 GAL. OF WATER ($95^{o}F$ MIN. TO $250^{o}F$ MAX)
COLLECTOR LOOP HEAT EXCHANGER HX-1	CAPACITY = 60 KBTU/HR COLLECTOR SIDE FLOW RATE = 4 GPM COLLECTOR SIDE TEMPERATURE DROP = $30^{o}F$ TES SIDE FLOW RATE = 12 GPM TES SIDE TEMPERATURE RISE = $10^{o}F$	CAPACITY = 70 KBTU/HR COLLECTOR SIDE FLOW RATE = 5 GPM COLLECTOR SIDE TEMPERATURE RISE = $27^{o}F$ TES SIDE FLOW RATE = 15 GPM TES SIDE TEMPERATURE RISE = $9.3^{o}F$
ENERGY DISTRIBUTION HEAT EXCHANGER HX-2	42 KBTU/HR WATER SIDE FLOW RATE = 16 GPM WATER SIDE TEMPERATURE RISE = $5.3^{o}F$ AIR SIDE FLOW RATE = 1200 CFM AIR SIDE TEMPERATURE RISE = 32 ^{o}F	30 KBTU/HR TES SIDE FLOW RATE = 16 GPM WITH $4^{o}F$ TEMPERATURE DROP AIR SIDE = $23^{o}F$ TEMPERATURE RISE AT 1200 CFM
RANKINE/A-C UNIT	1 UNIT HAVING 3-TON CAPACITY	1 UNIT HAVING 3-TON CAPACITY

PERFORMANCE - FORT WORTH:

1800 FT^2 SINGLE FAMILY RESIDENCE BUILDING BUILT TO ASHRAE 90-75 STANDARD
72% OF 24 MMBTU SEASONAL SPACE HEATING LOAD SATISFIED
60% OF 41 MMBTU SEASONAL SPACE COOLING LOAD SATISFIED
86% OF 16 MMBTU HOT WATER LOAD SATISFIED
PARASITIC ENERGY REQ'D 4.2 MMBTU, 6.1% OF SOLAR ENERGY SUPPLIED BY SYSTEM.

PERFORMANCE - WASHINGTON, D.C.

WASHINGTON, D.C. 1964 WEATHER
1800 FT^2 HOME BUILT TO ASHRAE STD 90-75
66% OF 56 MMBTU SEASONAL SPACE HEATING LOAD SATISFIED
78% OF 16 MMBTU SEASONAL SPACE COOLING LOAD SATISFIED
69% OF 20 MMBTU HOT WATER LOAD SATISFIED
PARASITIC ENERGY REQ'D 5.03 MMBTU, 8.0% OF SOLAR ENERGY SUPPLIED BY SYSTEM.

Table 2.2-4. System Description - HCMF Baseline

MAJOR SOLAR HARDWARE	FORT WORTH	WASHINGTON, D.C.
SOLAR COLLECTOR AREA	1839 FT^2 (124 TC-100 PANELS) 280°F MAX. OPERATING TEMPERATURE	1839 FT^2 (124 TC-100 PANELS) 280°F MAX. OPERATING TEMPERATURE
THERMAL ENERGY STORAGE	2760 GAL. OF WATER 95°F MIN. TEMPERATURE 250°F MAX. TEMPERATURE	2760 GAL. OF WATER 95°F MIN. TEMPERATURE 250°F MAX. TEMPERATURE
COLLECTOR LOOP HEAT EXCHANGER HX-1	CAPACITY = 430 KBTU/HR COLLECTOR SIDE FLOW RATE = 28 GPM " " TEMP. DROP = 30°F TES SIDE FLOW RATE = 56 GPM " " TEMP. RISE = 15°F	CAPACITY = 430 KBTU/HR COLLECTOR SIDE FLOW RATE = 28 GPM " " TEMP DROP = 30°F TES SIDE FLOW RATE = 56 GPM " " TEMP. RISE = 15°F
ENERGY DISTRIBUTION HEAT EXCHANGER HX-2	12 UNITS HAVING A CAPACITY OF 30 KBTU/HR WATER SIDE FLOW RATE = 6 GPM TEMP. DROP = 10°F AIR SIDE FLOW RATE = 1200 CFM TEMP. RISE = TBD°F	12 UNITS 30 KBTU/HR WATER SIDE FLOW RATE = 6 GPM TEMP. RISE = 10°F AIR SIDE FLOW RATE = 1200 CFM TEMP RISE = TBD °F
RANKINE/A-C UNIT	2 UNITS EACH HAVING 10-TON CAPACITY	2 UNITS EACH HAVING 10-TON CAPACITY
RANKINE COOLING TOWER	250 KBTU/HR TEMP (DB) = TBD TEMP (WB) = TBD	300 KBTU/HR TEMP (DB) = TBD TEMP (WB) = TBD

<u>PERFORMANCE - FORT WORTH</u>

14,400 FT^2 MULTI FAMILY RESIDENCE BUILDING BUILT TO ASHRAE 90-75 STD.
70% OF 119 MMBTU SEASONAL SPACE HEATING LOAD SATISFIED
61% OF 281 MMBTU SEASONAL SPACE COOLING LOAD SATISFIED
97% OF 131 MMBTU HOT WATER LOAD SATISFIED

PARASITIC ENERGY REQUIRED 32.6 MMBTU, 8.5% OF SOLAR ENERGY SUPPLIED BY SYSTEM

<u>PERFORMANCE - WASHINGTON, D.C.</u>

WASHINGTON, D.C 1964 WEATHER
14,400 FT^2 MULTI FAMILY RESIDENCE BUILT TO ASHRAE 90-75 STD.
54% OF 294 MMBTU SEASONAL SPACE HEATING LOAD SATISFIED
65% OF 61 MMBTU SEASONAL SPACE HEATING LOAD SATISIFIED
91% OF 180 MMBTU HOT WATER LOAD SATISFIED

PARASITIC ENERGY REQUIRED 34 MMBTU, 9.7% OF SOLAR ENERGY SUPPLIED BY SYSTEM

Table 2.2-5. System Description - HCCOM Baseline

MAJOR SOLAR HARDWARE	FORT WORTH	WASHINGTON, D.C.
SOLAR COLLECTOR AREA	8898 FT^2 (600 TC-100 PANELS) 280°F MAX. OPERATING TEMPERATURE	5932 FT^2 (400 TC-100 PANELS) 280°F MAX. OPERATING TEMPERATURE
THERMAL ENERGY STORAGE	13,350 GAL. OF WATER 95°F MIN. TEMPERATURE 250°F MAX. TEMPERATURE	8,900 GAL. OF WATER 95°F MIN. TEMPERATURE 250°F MAX. TEMPERATURE
COLLECTOR LOOP HEAT EXCHANGER HX-1	CAPACITY = 2100 KBTU/HR COLLECTOR SIDE FLOW RATE = 132 GPM TEMP. DROP = 32°F TES SIDE FLOW RATE = 264 GPM TEMP. RISE = 16°F	CAPACITY = 1400 KBTU/HR COLLECTOR SIDE FLOW RATE = 88 GPM TEMP. DROP = 32°F TES SIDE FLOW RATE = 176 GPM TEMP. RISE = 16°F
ENERGY DISTRIBUTION HEAT EXCHANGER HX-2	10 UNITS EACH HAVING A CAPACITY OF 180 KBTU/HR WATER SIDE FLOW RATE = 18 GPM TEMP. DROP = 20°F AIR SIDE FLOW RATE = 4000 CFM TEMP. RISE = 42°F	10 UNITS EACH HAVING A CAPACITY OF 150 KBTU/HR WATER SIDE FLOW RATE = 15 GPM TEMP. DROP = 20°F AIR SIDE FLOW RATE = 4000 CFM TEMP. RISE = 35°F
RANKINE/A-C UNIT	10 UNITS EACH HAVING 10-TON CAPACITY	10 UNITS EACH HAVING 10-TON CAPACITY
RANKINE COOLING TOWER	1.5 MMBTU/HR TEMP (DB) = TBD TEMP (WB) = TBD	1.5 MMBTU/HR TEMP (DB) = TBD TEMP (WB) = TBD

PERFORMANCE - FORT WORTH

20,000 FT^2 COMMERCIAL BUILDING BUILT TO ASHRAE 90-75 STD.
85% OF 1847 MMBTU SEASONAL SPACE HEATING LOAD SATISFIED
54% OF 595 MMBTU SEASONAL SPACE COOLING LOAD SATISFIED
99% OF 44 MMBTU HOT WATER LOAD SATISFIED

PARASITIC ENERGY REQ'D 160 MMBTU, 8.3% OF SOLAR ENERGY SUPPLIED BY SYSTEM

PERFORMANCE - WASHINGTON, D.C.

20,000 FT^2 COMMERCIAL BUILDING BUILT TO ASHRAE 90-75 STD.
60% OF 1330 MMBTU SEASONAL SPACE HEATING LOAD SATISFIED
51% OF 680 MMBTU SEASONAL SPACE COOLING LOAD SATISFIED
95% OF 55 MMBTU HOT WATER LOAD SATISFIED

PARASITIC ENERGY REQ'D 161 MMBTU, 13.5% OF SOLAR ENERGY SUPPLIED BY SYSTEM

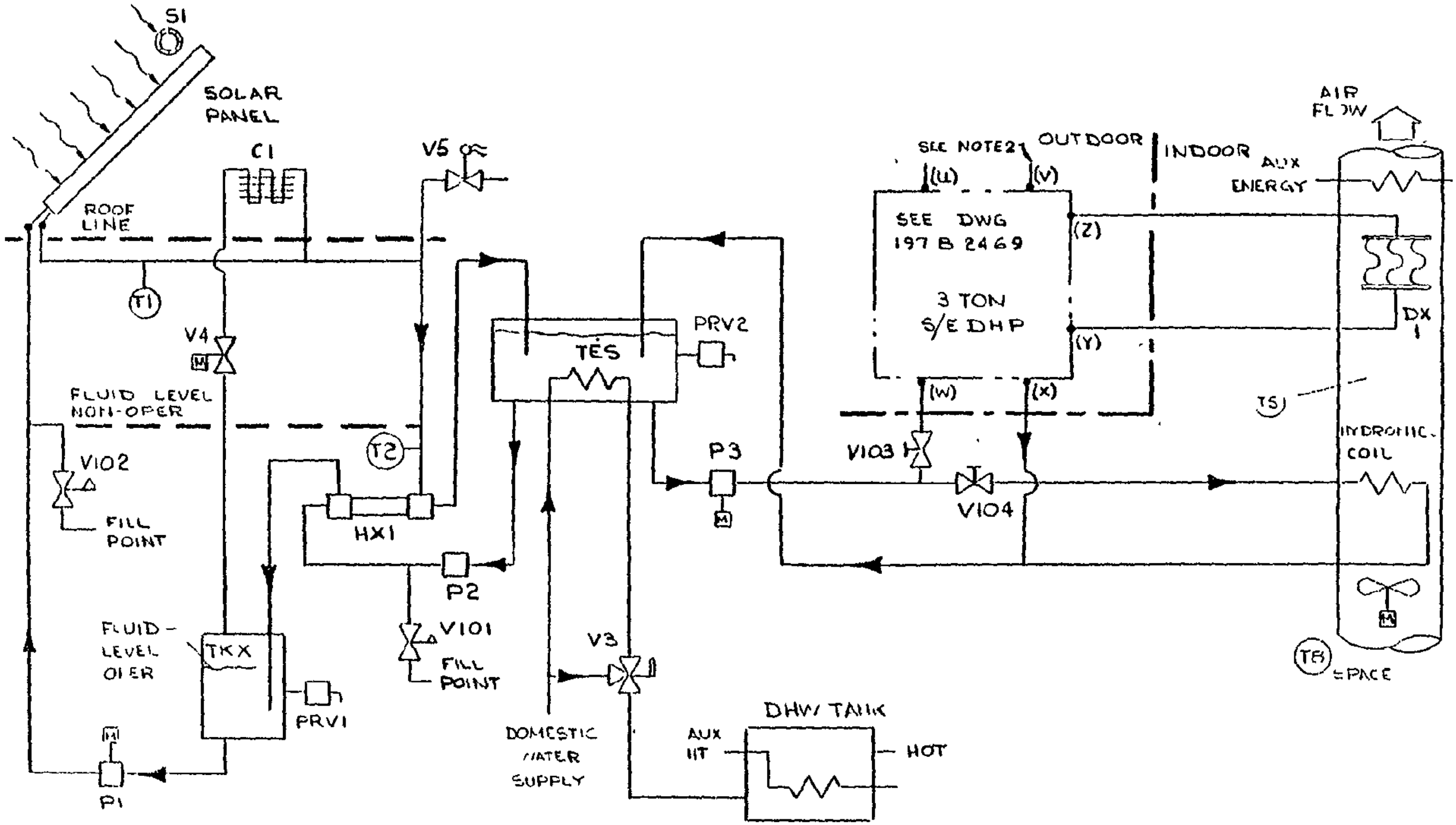

Figure 2.2-4. System Schematic, Heating and Cooling Single Family

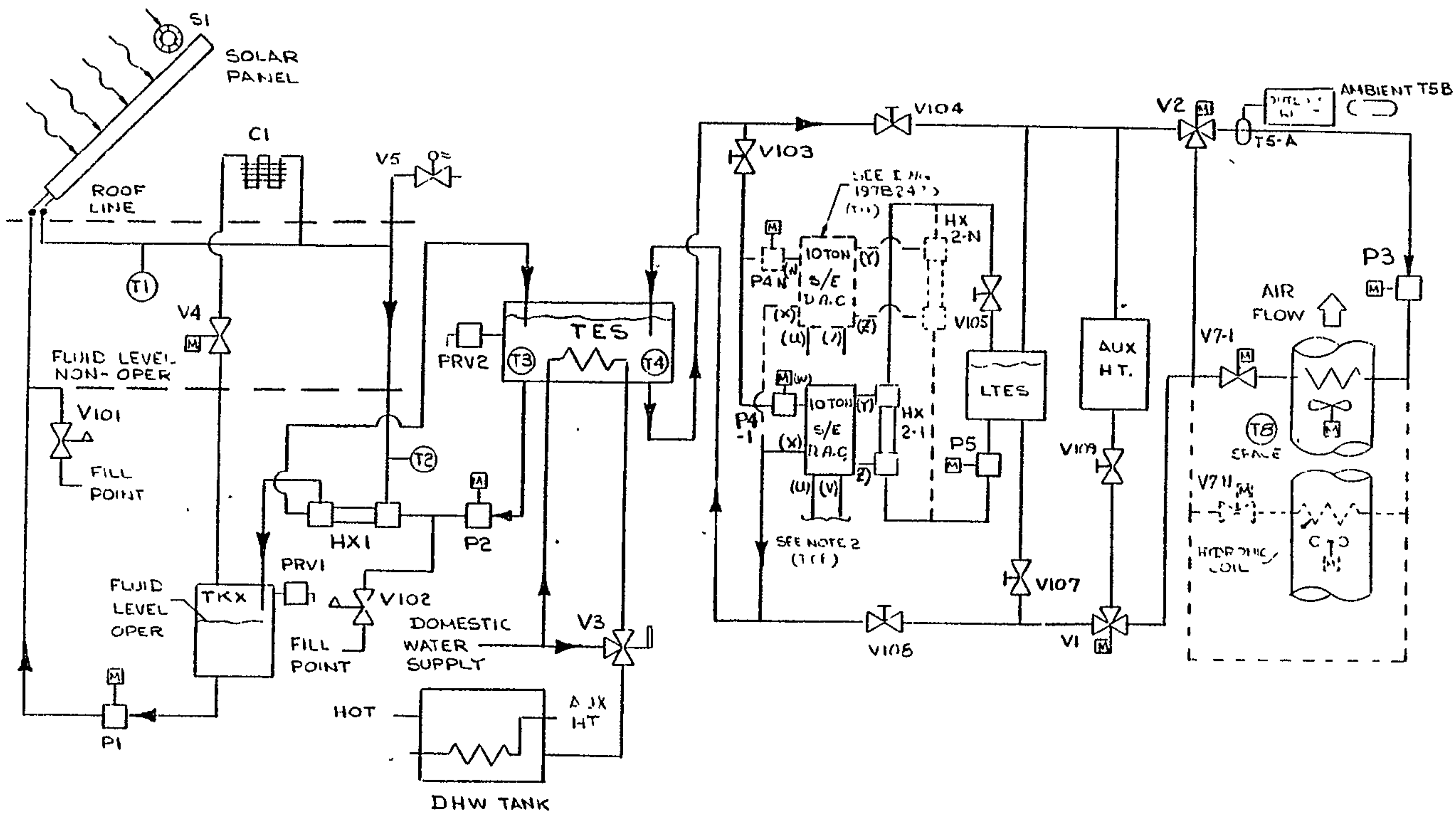

Figure 2.2-5. System Schematic, Heating and Cooling Multi-Family

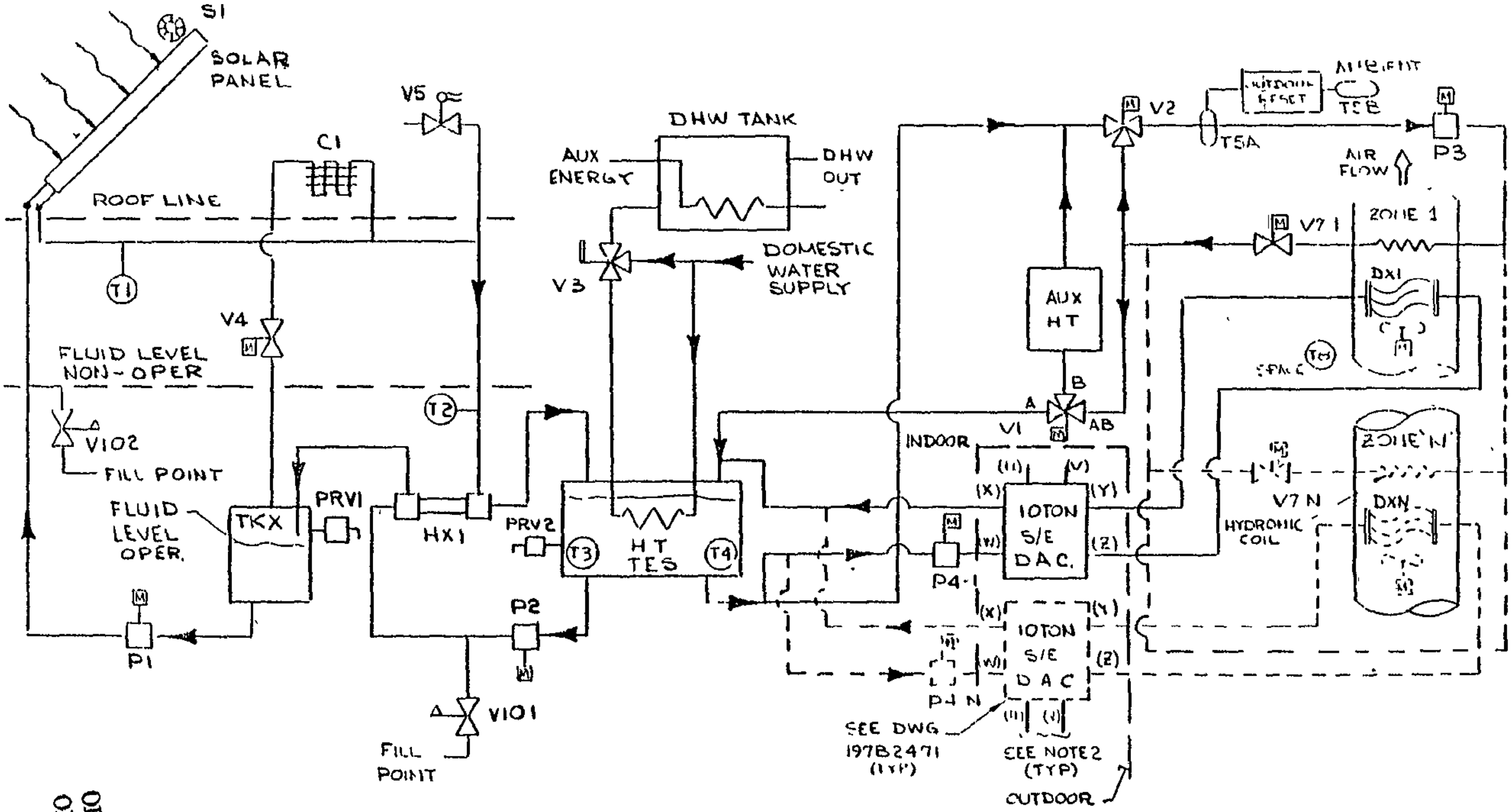

Figure 2.2-6. System Schematic, Heating and Cooling Commercial

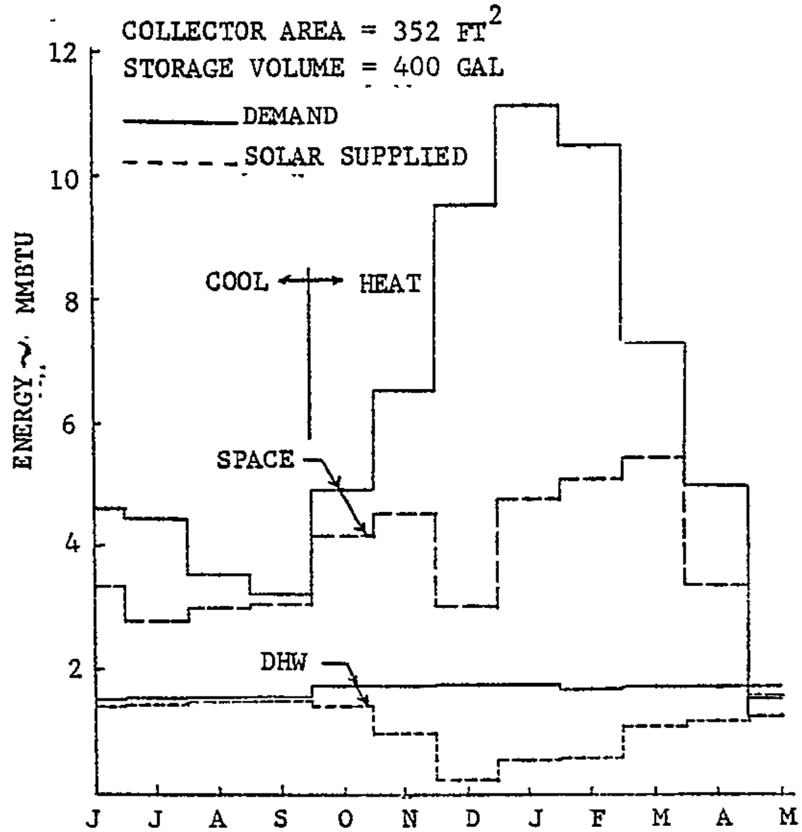

Figure 2.2-7. System Performance, HCSF Baseline, Washington, D.C.

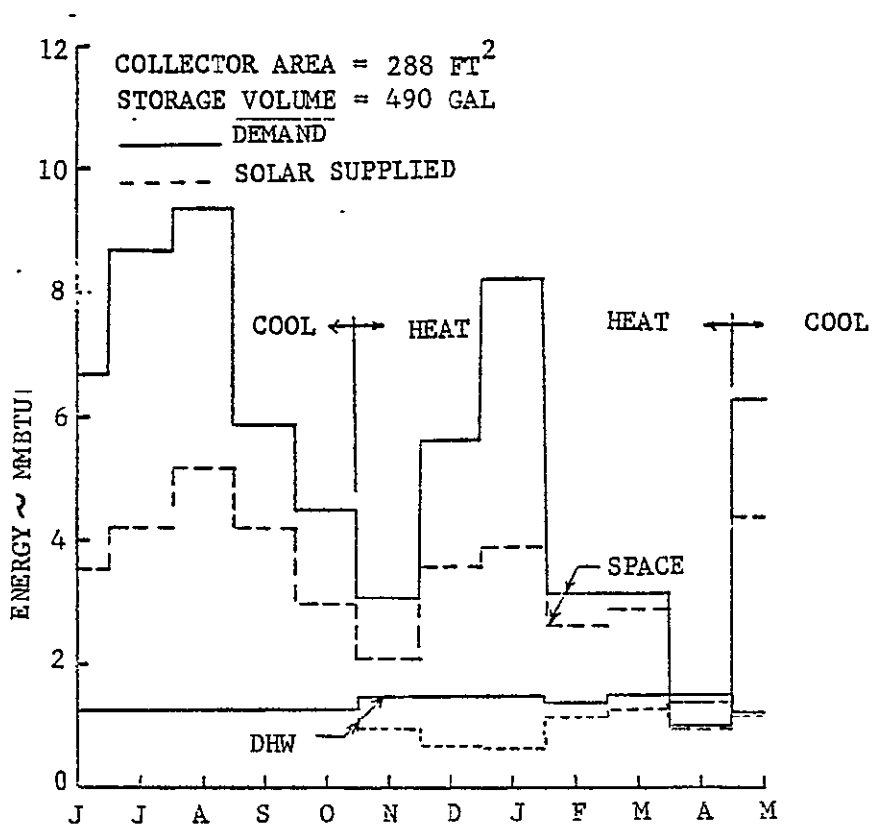

Figure 2.2-8. System Performance, HCSF Baseline, Fort Worth, Texas

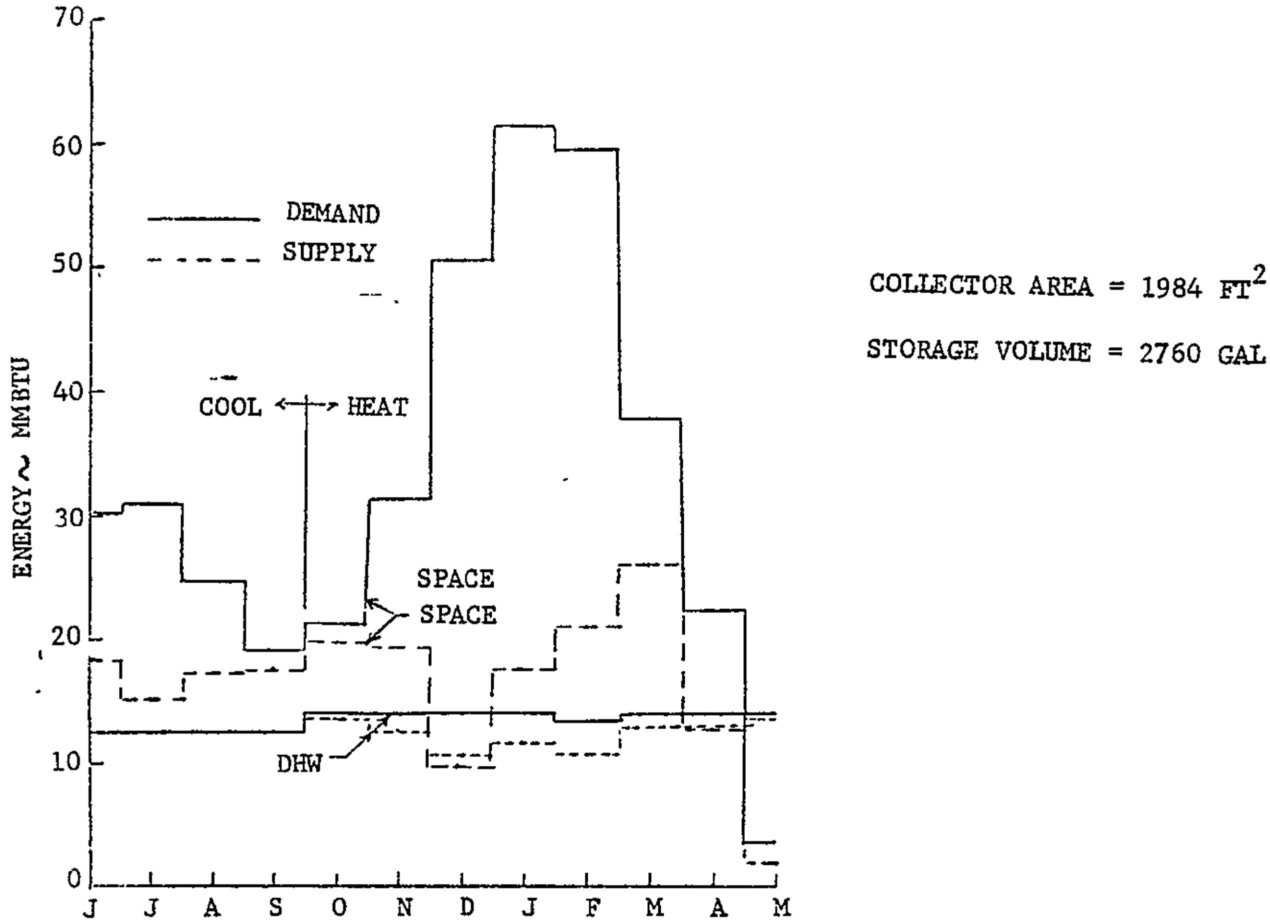

Figure 2.2-9. System Performance, HCMF Baseline, Washington, D.C.

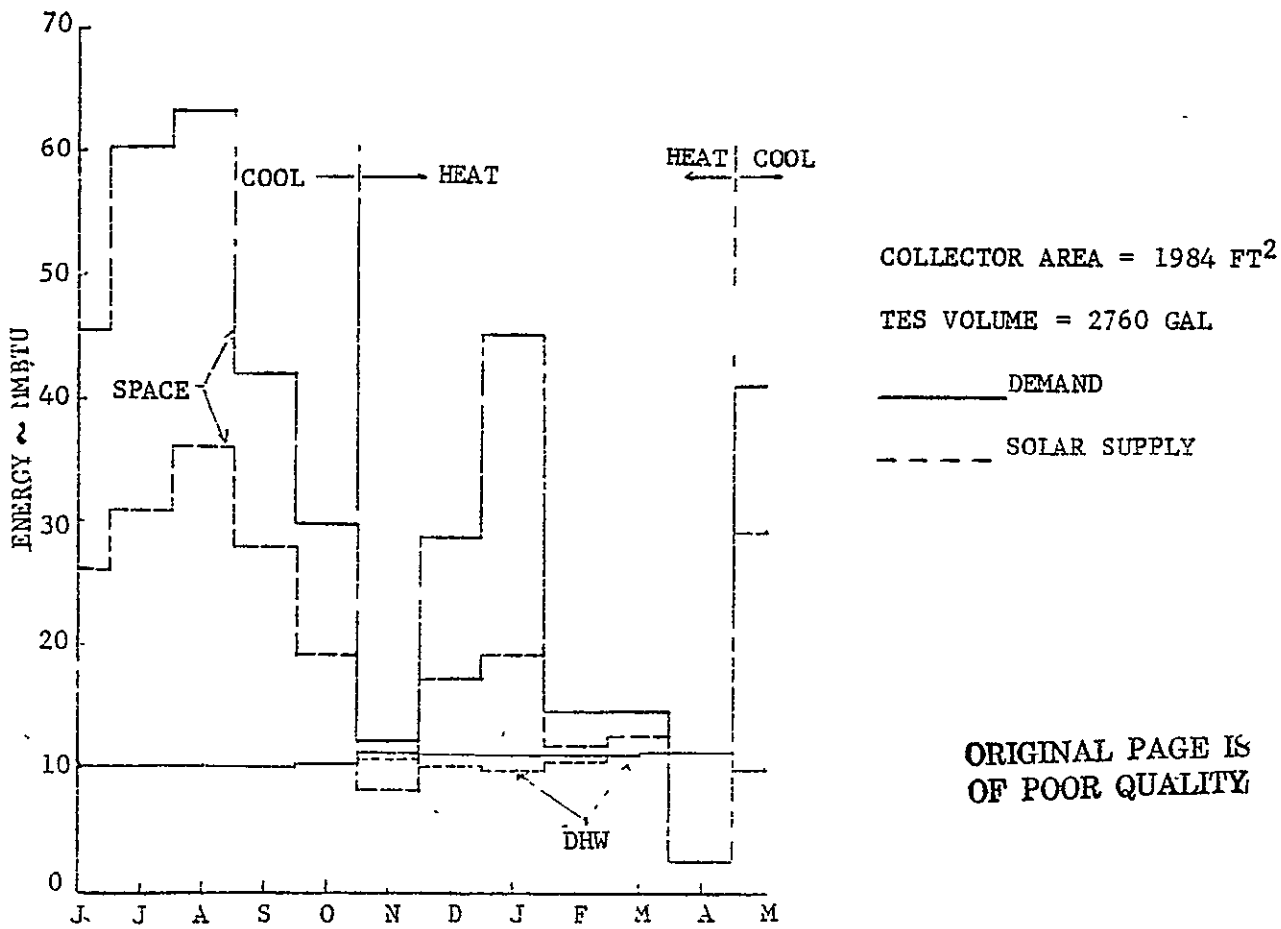

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Figure 2.2-10. System Performance, HCMF Baseline, Fort Worth, Texas

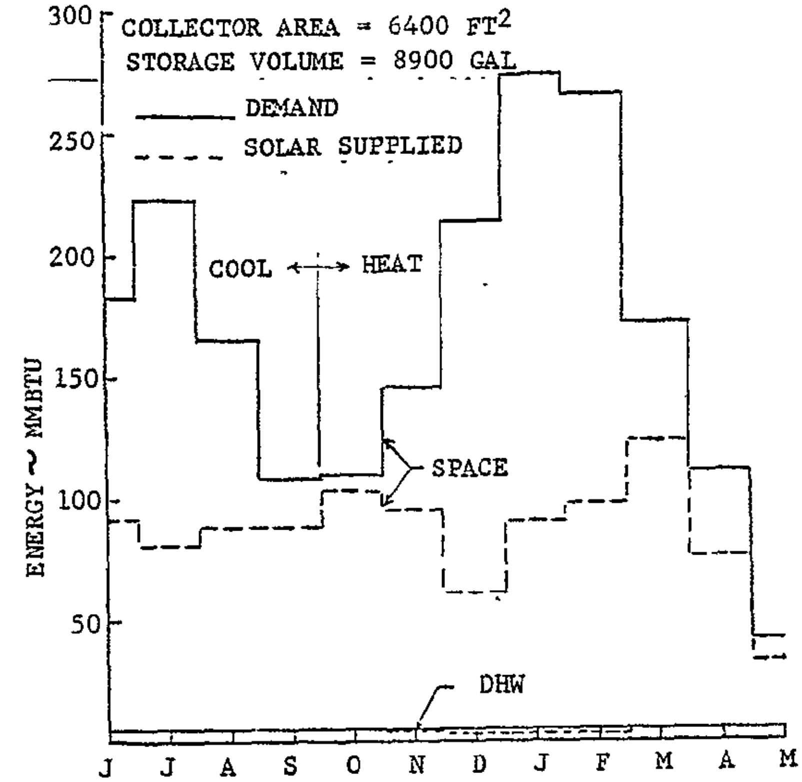


Figure 2.2-11. System Performance, HCCOM Baseline, Washington, D.C.

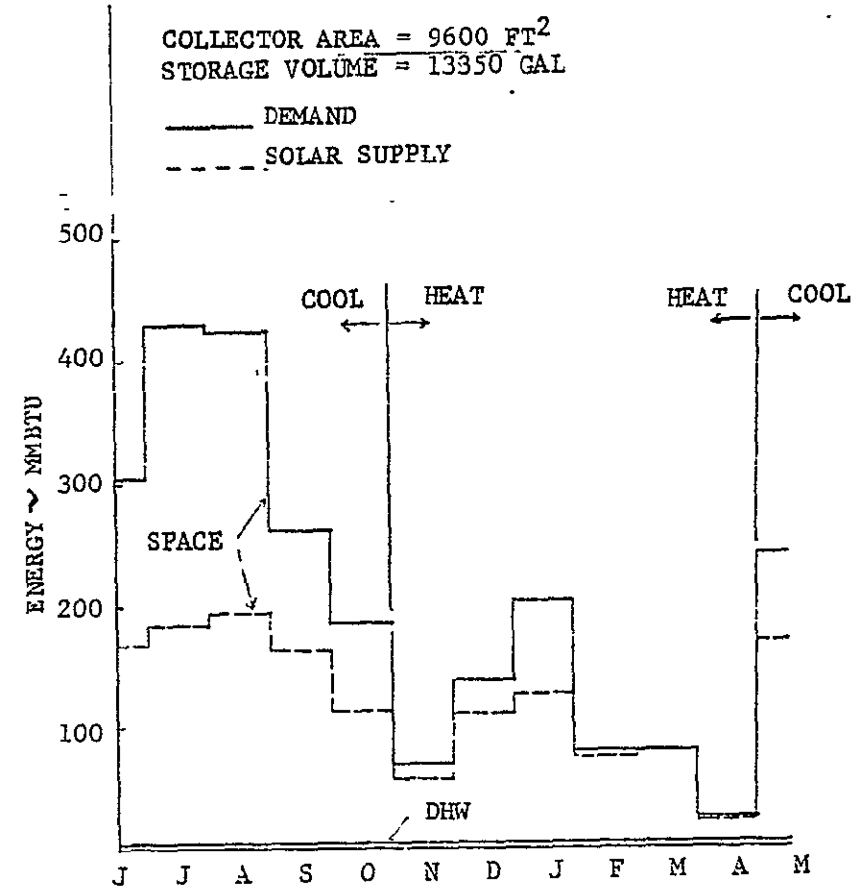


Figure 2.2-12. System Performance, HCCOM Baseline, Fort Worth, Texas

2.2.3 SYSTEM TRADE STUDIES

Trade studies have been performed to establish system sizes and configurations best suited to the loads developed for the typical buildings developed and defined during the heating only study.

Initial trade studies made to support system configurations were reported on in the first Quarterly Report. The results led to the following conclusions:

1. The size of the solar driven air conditioner should be smaller than the electric driven machine
2. The solar driven machine should only operate in the cooling mode.

A number of configurations were studied for the low temperature Rankine system (LTR) as summarized in Table 2.2-6.

Table 2.2-6. LTR Configurations

CONF.	NOMINAL CAPACITY	TYPE OF A/C EVAPORATOR*	TYPE OF LTR CONDENSOR**	OPERATING MODE***
A	3T	Dx	AIR	MATCHED
B	10T	Ch.	W	MATCHED
C	10T	Dx	W	MATCHED
D	3T	Dx	AIR	MOTOR BOOST
E	10T	Dx	W	MOTOR BOOST
F	10T	Ch	AIR	MATCHED

* Dx is a direct expansion coil, Ch. refers to a chiller.

** The LTR condensor is either air cooled, or water cooled.

*** Matched operation refers to a directly coupled expander and compressor. Motor boost refers to an electric motor clutched to the expander for load sharing.

The 3 ton systems were evaluated for the single family residence and the 10 ton systems were applied to both the multi-family and the commercial buildings. Heating and domestic hot water approaches are similar to the heating only configurations with the exception that a heat pump supplies part of the auxiliary energy requirements.

The parameters that were varied included

1. Collector area
2. High temperature TES volume
3. Low temperature TES volume
4. HX-1 size
5. Flow rate to the LTR Vapor Generator
6. SDHP performance

The fixed parameters for all studies included the use of the TC-100 vacuum tube collector with a fixed orientation, facing south, tilted at the latitude angle. Tilt effects on the TC-100 collector amount to less than a 4% deviation in collected energy over a range of $\pm$ 15^{o} about the latitude.

2.2.3.1 Single Family Residence (HCSF) Configuration

The single family residence's two possible LTR configurations (A & D of Table 2.2-6) were examined to define which system would provide the optimum performance. Operational capacities and performance characteristics of the LTR/heat pump system are based on the analyses described in paragraph 2.3.2.10.

Figure 2.2-13 shows the influence of collector area on the energy delivered by the solar system. The storage volume was kept at 1.5 gal/ft^2 of collector area and a 95^{o} minimum temperature (in heating) and a 250^{o} maximum (for cooling) were used.

Figure 2.2-14 illustrates how insensitive the specific TES volume is in system performance beyond 1.0 gal/ft^2 of collector. This holds true for both heating and for cooling as well as over a wide range of collector array sizes. One interesting result is that continually increasing the TES size for cooling can lead to performance degradation. The tank heat losses become significant at the high temperatures required for cooling.

A comparison was made between configurations A and D, the SDHP matched operation and the SDHP motor boost mode for a typical case. The results presented in paragraph 2.2.3.6 showed that while more solar energy was utilized to cool the building, the total auxiliary energy required to operate the solar system increased. On that basis, the motor boost configuration is not as attractive from systems performance considerations.

An analysis was performed to determine the effect of the solar fluid flow rate and LTR vapor generator pressure drop on SDHP performance, and Figure 2.2-15 contains the results. Shown are the influence of the solar heated fluid flow rate and the vapor generator (V/G) pressure drop on the LTR delivered horsepower, energy required and Rankine cycle efficiency at the 3 ton design point. Decreasing the flow rate decreased the horsepower delivered. However, the energy required by the vapor generator also decreased and the net effect is only a small loss in cycle efficiency. A more important effect is the fact that as horsepower decreases, so too does the speed of the LTR expander/compressor and the output capacity of the heat pump.

2.2.3.2 Multi-Family Residence (HCMF) Configuration

Tradeoffs for the multi-family residence included collector area effects, use

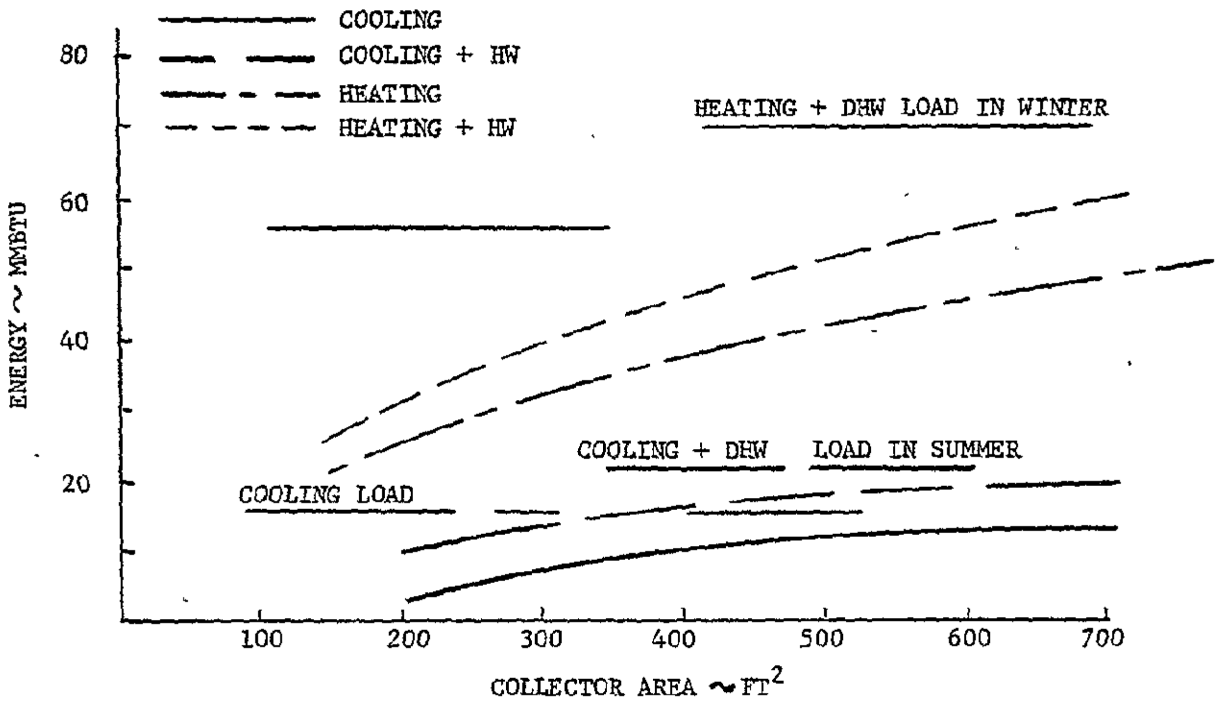


Figure 2.2-13. Collector Area Effects

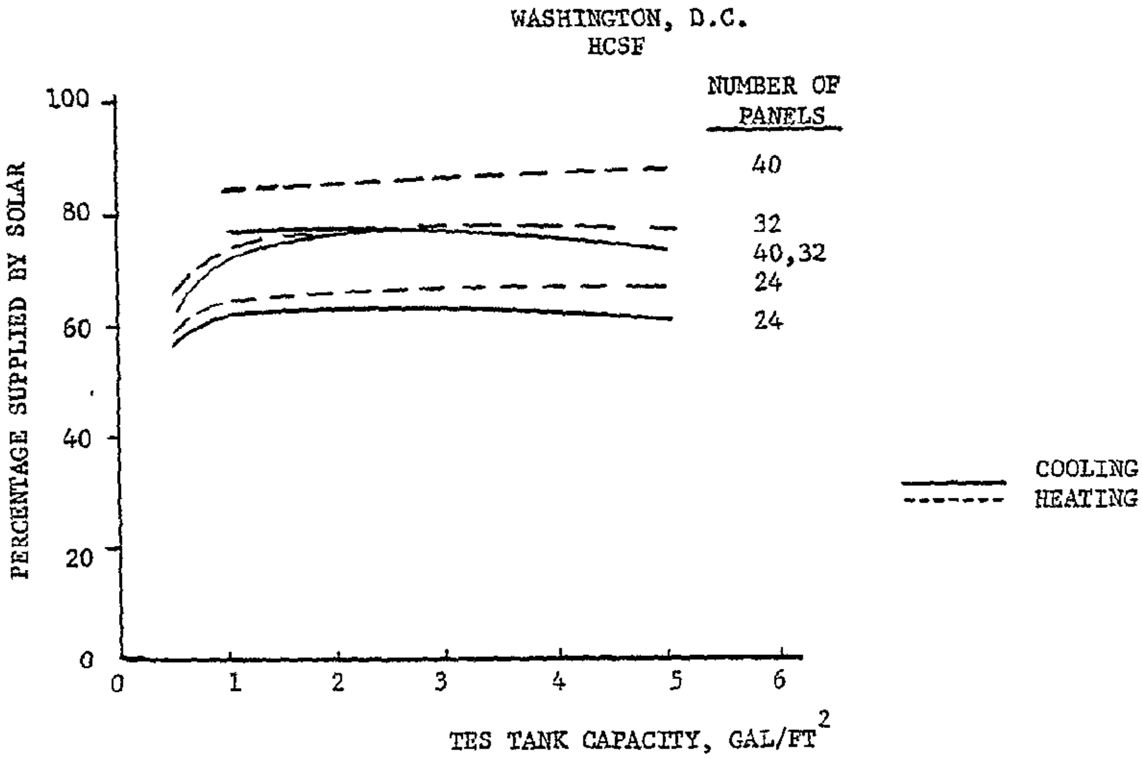


Figure 2.2-14. Effect of TES Volume on System Performance HCSF

use of direct expansion evaporators vs. a chiller evaporator, and the effect of cold storage tank volume for the chiller system. Tradeoffs on hot storage TES volume and motor boost vs. matched operation trends performed for the HCSF case were not repeated based on the similarity of application and the trends found during the heating only studies.

Figure 2.2-16 shows the collector area effects making use of preliminary expander performance to determine the operating regime.

The curves use the S/EDHP's system with direct expansion coils. A data point using the chiller system is shown for the cooling season. The performance of the chiller systems is close to the performance of the direct expansion system but not superior to it. The system with a chiller must operate at a lower COP than the direct expansion system due to the lower refrigerant temperatures required. However, the use of a cold storage system may allow partial recovery of system efficiency due to off peak cooling capability.

The effect of the size of the cold storage tank was also evaluated using a 1860 ft^2 collector array shown in Figure 2.2-17. Small increases in system performance are observed when the LTES's capacity is increased. Some LTES capacity which will be defined later is required to minimize the cycling (on/off) of the cooling machine.

Multi-family dwellings involve the choice of centralized HVAC units with distribution systems or separate small systems dedicated to each unit. In either case current recommended practice requires that the energy consumption of the individual units be measured. Cooling of multi-unit buildings practically involves the use of a chilled water system or individual units. The technical

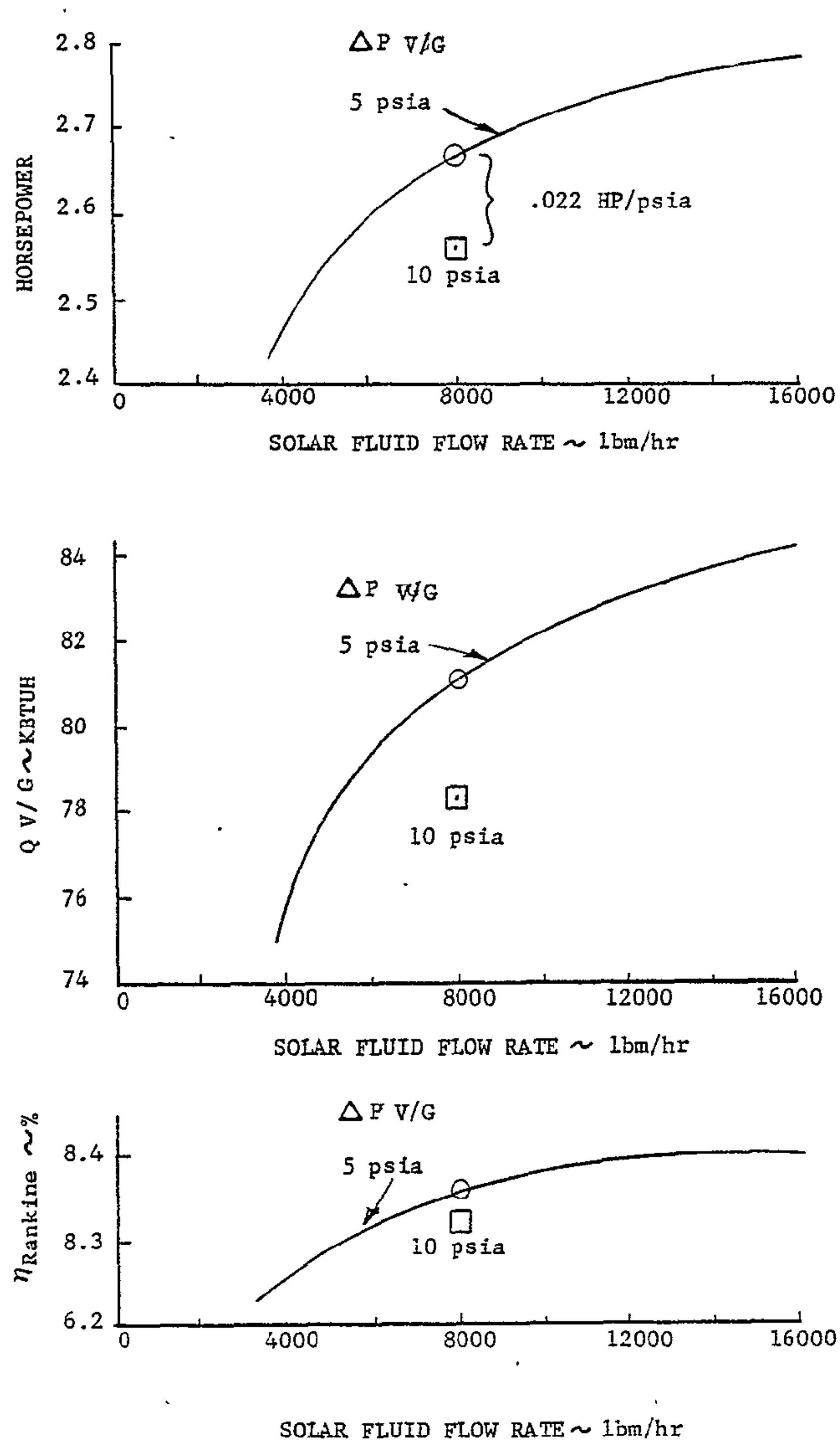


Figure 2.2-15. Effect of W Solar & ΔP V/G on 3 Ton

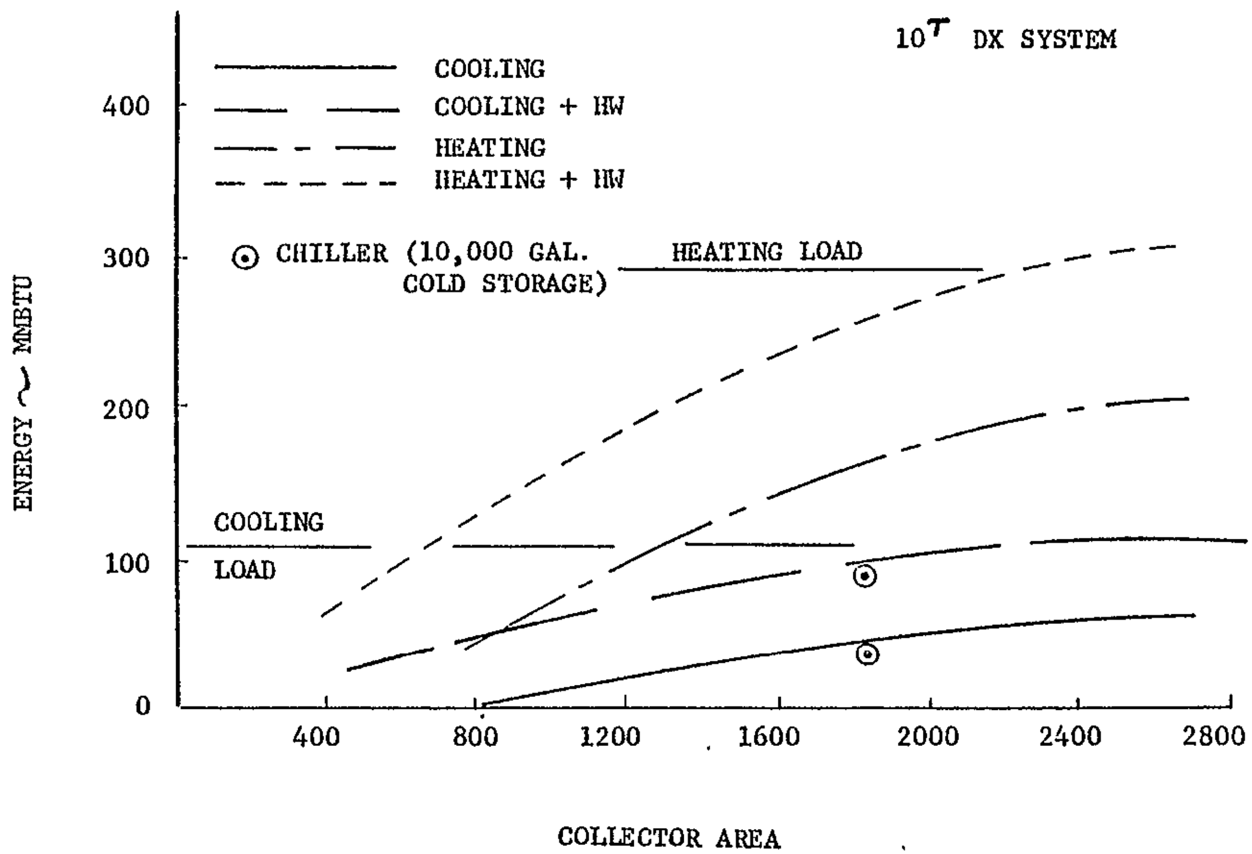


Figure 2.2-16. Collector Area Effects, Washington, D.C., HCMF

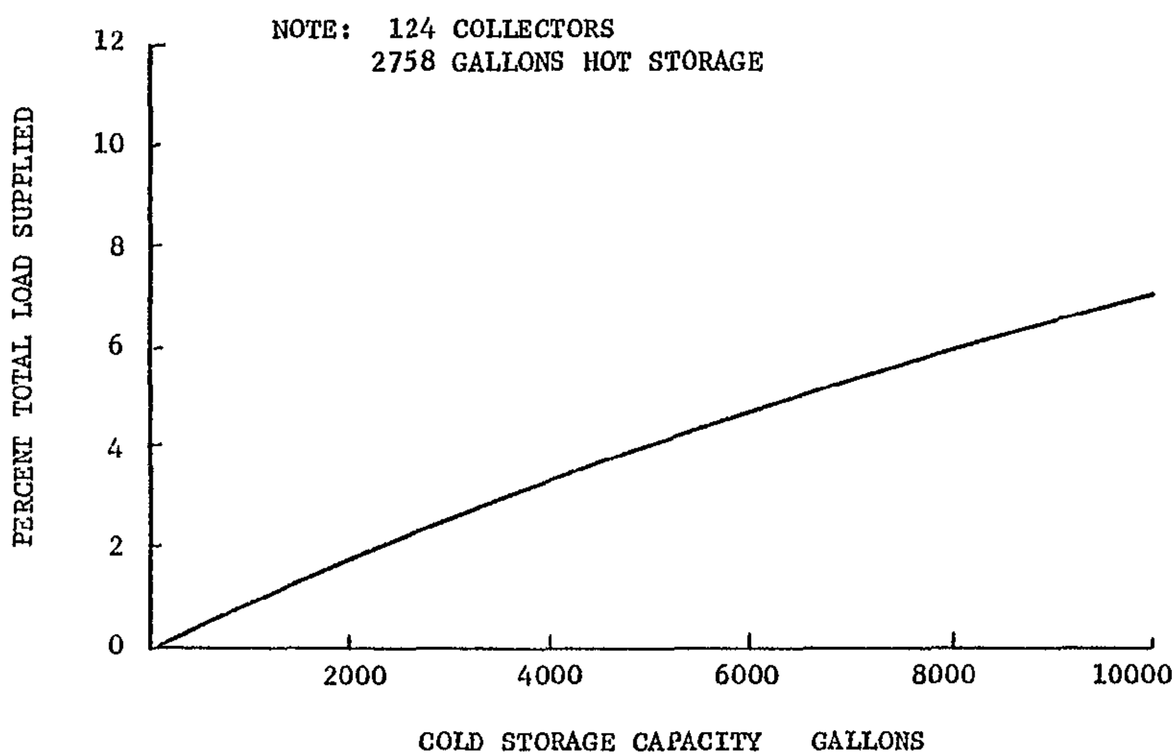


Figure 2.2-17. System Performance, Cold Storage Capacity Effects, Multi-Family Residence

problems with air distribution from a central cooling unit are difficult and most known solutions are energy wasteful. Therefore, the program choice was a central unit with chiller or individual units.

2.2.3.3 Commercial Building Application

Studies were performed on the commercial applications in a similar manner to those for the multi-family application. Figure 2.2-18 shows the collector area influence using the analytical expander model to determine SDHP performance. The comparison between the DX system and the chiller system is included for a single collector area. As discovered in the studies of the HCMF case, the chiller with cold storage performed close to but not superior to the DX case with no cold storage capability. The influence of hot TES volume was studied for a single collector area with identical results found from the HCSF studies.

2.2.3.4 Solar Loop Heat Exchanger

The solar loop heat exchanger was investigated to optimize and standardize its sizing. A comparison of Figures 2.2-19 and 2.2-20 indicates that an optimum UA product exists for the presently proposed collector system. The UA product is different for the different building types in different climates. A non-demensional approach was found which will collapse all the data into one line as shown in Figure 2.2-21. In Figure 2.2-21, a nominal U of 300 Btu/hr $ft^2 {}^oF$ is used but areas with other U's can be evaluated as long as the UA product remains consistent. The data points which fall significantly below the curve show the effects of the small sizes of the TES in the single family home coupled with the other system components. The dashed arrow indicates the performance is improved when the TES size is increased.

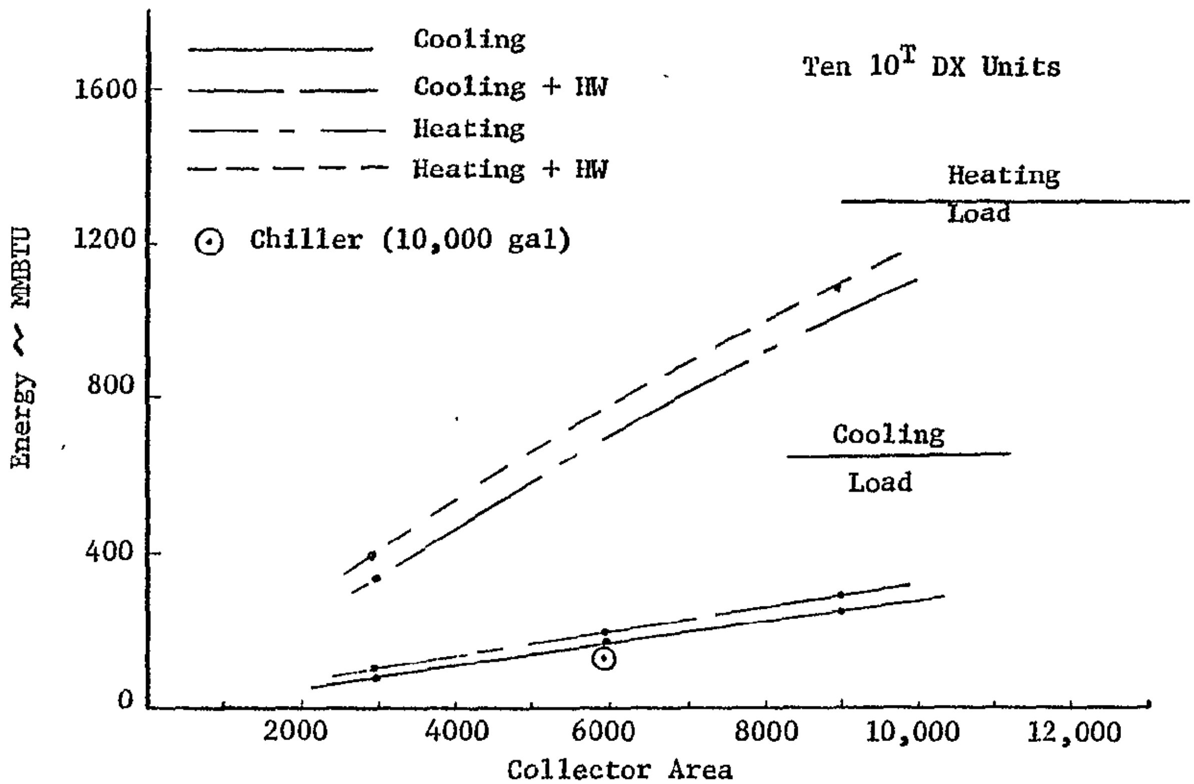


Figure 2.2-18. Collector Area Effects, Washington, D.C., HCCOM

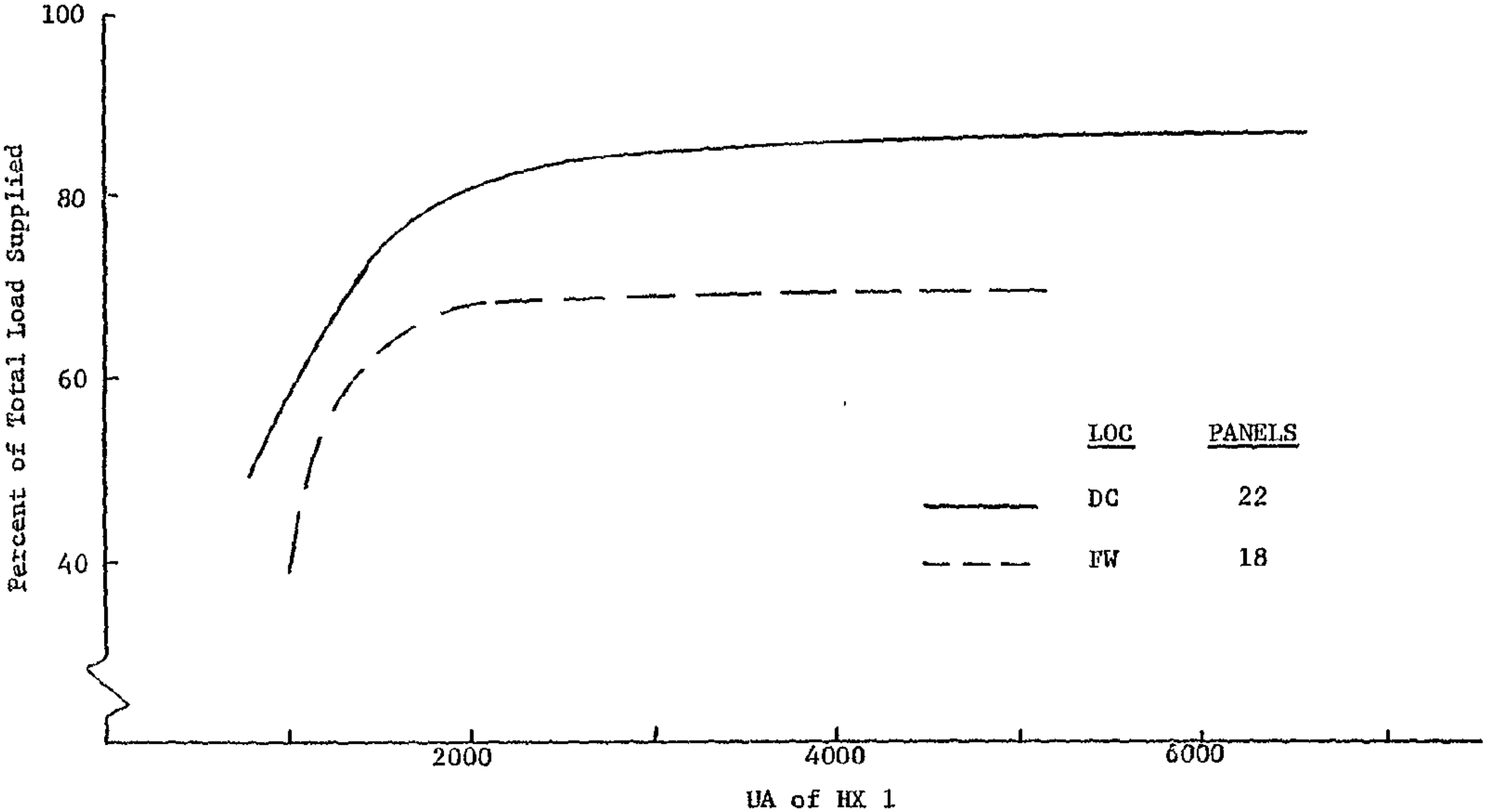


Figure 2.2-19. HCSF Baseline Configuration,
Heat Exchanger Area Dependency

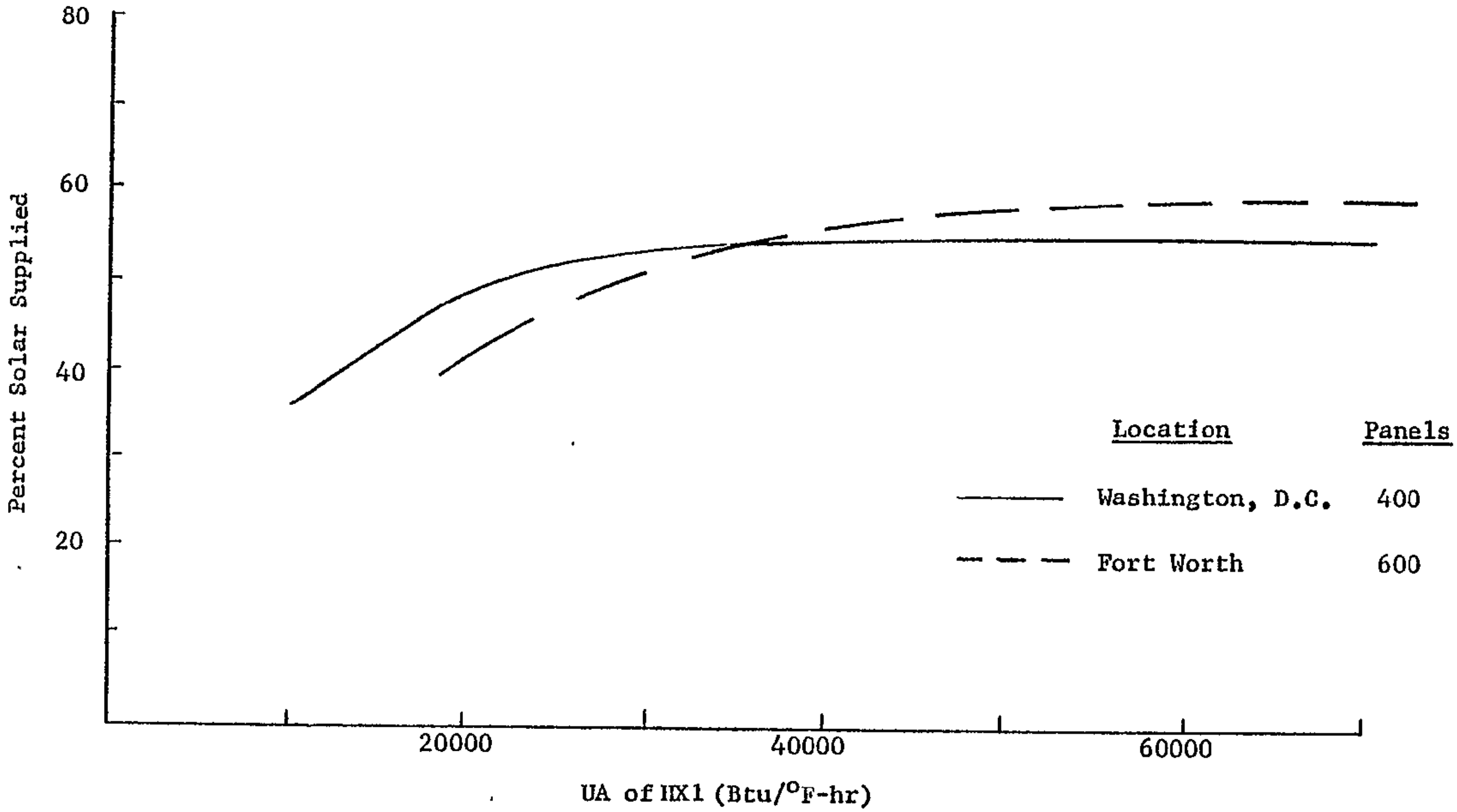


Figure 2.2-20. HCCOM Baseline Configuration Heat Exchanger Area Dependency

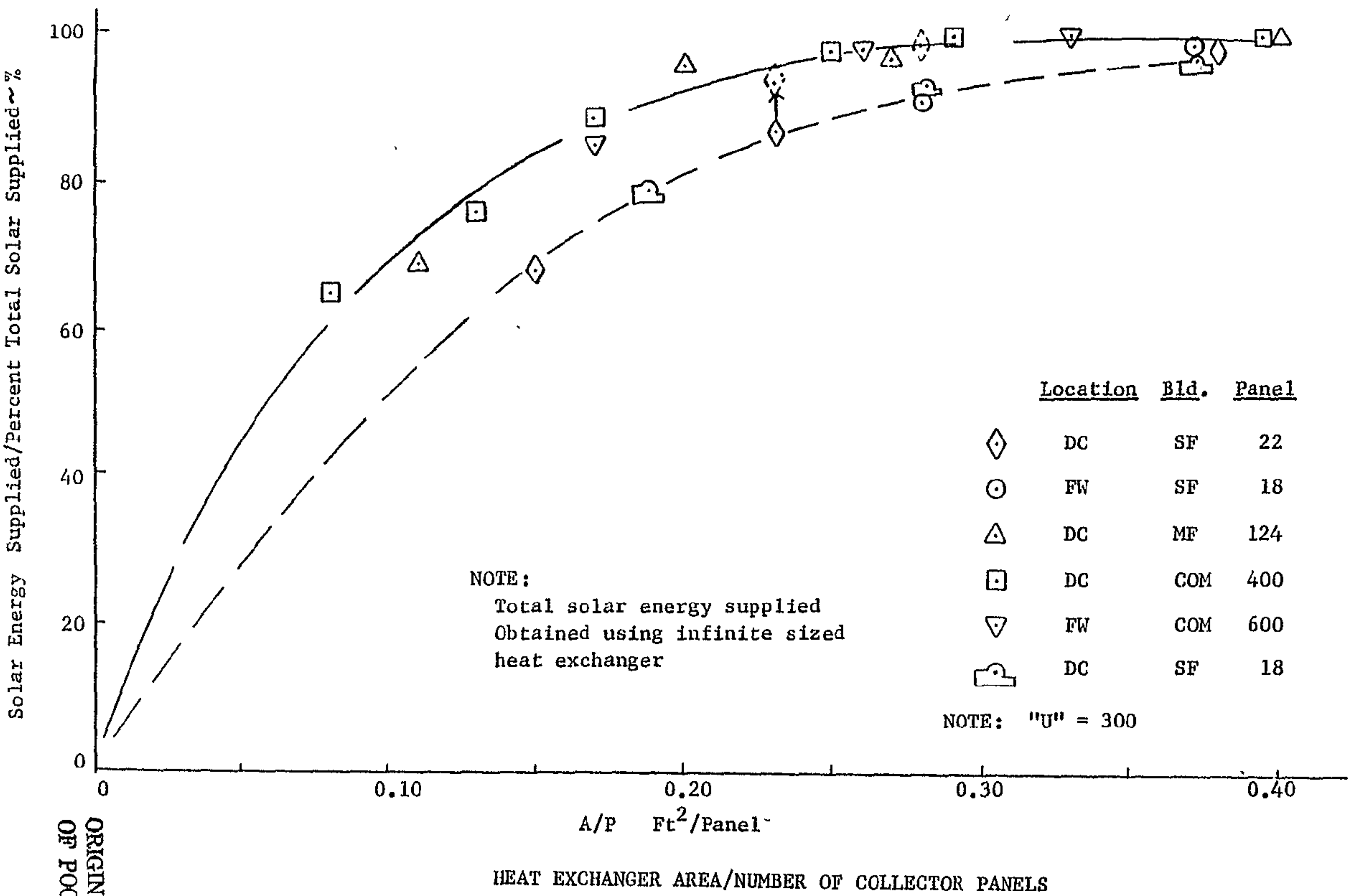


Figure 2.2-21. Normalized System Performance

2.2.3.5 System Simulation Computer Code Update

The computer code SSS, used in preliminary system design and analysis, has been updated to accommodate a building load tape as an input to the code. The code takes the output from the Building Transient Thermal Loads (BTTL) program which determines heating and cooling energy demands using a simple finite difference mathematical technique to calculate time-varying temperature profiles of elements of a thermal model for a building. The BTTL and SSS codes will be used in the final design simulation for test site installation of solar systems.

The control logic for on-off operation of solar driven heat pump has also been updated to simulate the temperature deadband control. The fraction of hour of SDHP in operation is determined by the thermal storage task set temperatures and the rate difference between incoming solar energy from the collector and outgoing energy to the Rankine vapor generator. The change to deadband temperature control resulted in no significant change of parasitic power requirement from the non-deadband system.

2.2.3.6 Comparison of 3 ton LTR Matched Operation vs Motor Boost Operation

Analysis was made to determine the parasitic power requirement for two different LTR operating configurations. Motor Boost vs Matched. The comparison is shown in Table 2.2-7 for single family residence baseline system in Washington, D.C. The results showed that with the Matched mode, the LTR operated for lesser hours with more electric heat pump back up as auxiliary energy. However, the Rankine engine parasitic requirement for operating in the Motor Boost mode exceeded the energy saving of running lesser electric heat pump than the Matched mode. Thus, overall parasitic requirement for Motor Boost system is approximately 5% more than that of the Matched system.

Table 2.2-7. Comparison of LTR Matched Operation and Motor Boost Operation

	Matched Operation	Motor Boost
Rankine Operating hour	225	261
Electric Heat Pump parasitic (KBTU)	2152	1376
Rankine Engine Parasitic (KBTU)	1085	1259 + 761 (Motor Power)
Pumps Parasitic (KBTU)	2096	2125
Hot Water Auxiliary (KBTU)	309	461
Total System Parasitic (KBTU)	5644	5980

2.3 SYSTEM DEVELOPMENT (WBS 1.2.2)

2.3.1 HEATING SYSTEMS (WBS 1.2.2.1)

2.3.1.1 Collector (WBS 1.2.2.1.1)

The collector development task includes the design and performance verification of the basic collector, the design activities related to integrating the collector into standard roof structures and the design and development of a heat transfer loop of which the collector forms a part. Activities in all three areas have continued during the second reporting quarter for the contract effort and significant accomplishments are summarized in the following paragraphs.

2.3.1.1.1 Collector Design and Performance Verification

A collector was shipped to the Florida Solar Energy Center (FSEC) for independent verification of collector performance while the GE facility was being prepared. Even though the Center could only test to 200°F, it was felt that verification up to 200°F would help establish a confidence level in previously taken GE data. Results of FSEC testing were disappointing. Because of bad weather, inexperience of testing at the higher temperatures and a clogging problem produced by pumping well water through the serpentine, all of the data points taken were suspect.

The GE building B facility was completed and made operational during the reporting period. First one collector, and then a pair of collectors were tested. The results of the testing are presented in Table 2.3-1.

In Table 2.3-1, the computer calculated performance at the given test conditions is compared with the measured test conditions. Test points 1 through 15 were run with a defective shroud. Correlation was good, except at the higher temperatures where the defective shroud radiated energy outward, thereby affecting the performance significantly. The defective shroud was not as apparent at the lower

Table 2.3-1 Instantaneous Thermal Efficiency Test

Data Correlation for TC-100 Collectors

TEST	HOUR	INCIDENT ANGLE	TEMPERATURE (°F) FLUID	TEMPERATURE (°F) AMBIENT	INSOLATION (Btu/hr/ft^2)	THERMAL EFFICIENCY Calc	THERMAL EFFICIENCY Test	COMMENTS
1	10:34	24.0	139	43	256.9	50.5	48.5	One TC-100 Collector with one bad shroud
2	11:03	17.3	138	43	267.9	52.5	52.5	
3	10:58	18.5	118.9	47.2	257.2	52.8	52.0	
4	11:45	8.0	134.8	48	257.7	55.7	53.5	
5	10:27	25.8	225.7	52.1	245	45.9	38.1	
9	11:14	15.0	245	35.6	269.3	48.4	39.4	
11	12:14	5.4	261.4	57.8	270.7	53.1	37.2	
12	10:41	22.8	279	19.9	261.5	43.7	28.2	
14	12:58	12.1	291	24.6	264.7	46.3	40.5	
15	14:04	26.7	293.8	24.9	220.1	39.0	28.1	
16	13:06	13.7	263	32	255.2	47.6	45.1	One TC-100 Collector with all good shrouds
17	13:44	22.2	269	32.3	231.8	43.7	36.2	
18	11:49	8.8	255	19.3	311.6	52.1	47.1	Two TC-100 Collectors with one bad shroud
19	10:20	27.7	253	32	245.6	43.1	42.6	Two TC-100 Collectors with all good shrouds
20	11:15	15.5	263	32	268.5	48.0	49.6	
21	12:24	7.1	263	34	264.6	51.9	51.4	
22	13:21	17.1	260	36	240.6	46.7	45.1	
23	14:25	28.6	256	37	191.1	39.8	31.8	

temperatures because the radiative power of the coated surface is significantly less. Runs 16 and 17 were with all 10 shrouds operational and correlation was better.

Two collectors were then tested in series to increase the ΔT across the insolated area thereby improving measurement accuracy. Correlation was better even with one bad shroud. Data point 23 appears significantly low, but the time of measurement was approximately 2 hours after solar noon and there is a significant dip in concentration ratio at or near that point. A 10 minute error in reporting the time or the time of solar noon could account for the error.

The overall conclusion from the data is that the collector will meet its performance predictions. The good correlation between analytical prediction and actual test results confirms the adequacy of the computer model which is then used to predict annual performance. Data is continuously being taken at the present time to insure that extreme test conditions of low insolation, declination angle and daily solar angle will also correlate with predicted results.

2.3.1.1.2 Collector Integration

A collector manifold design has been formulated which appears to be universally acceptable for most mounting situations. Figure 2.3-1 illustrates this design and identifies its key components. The pipe is Type L copper tubing, which offers trouble free service due to its excellent corrosion resistance. It is readily available and cost effective due to a combination of easy handling, forming, joining and service life, and is preferred by most tradesmen consulted on desirability of various materials. All interconnections are by commercially available standard flared brass water tube and copper wrought and cast fittings. If appropriate brazing alloys are used the rated working pressures ($>$300psi) meet the desired safety factor (5X) for the collector's service temperatures.

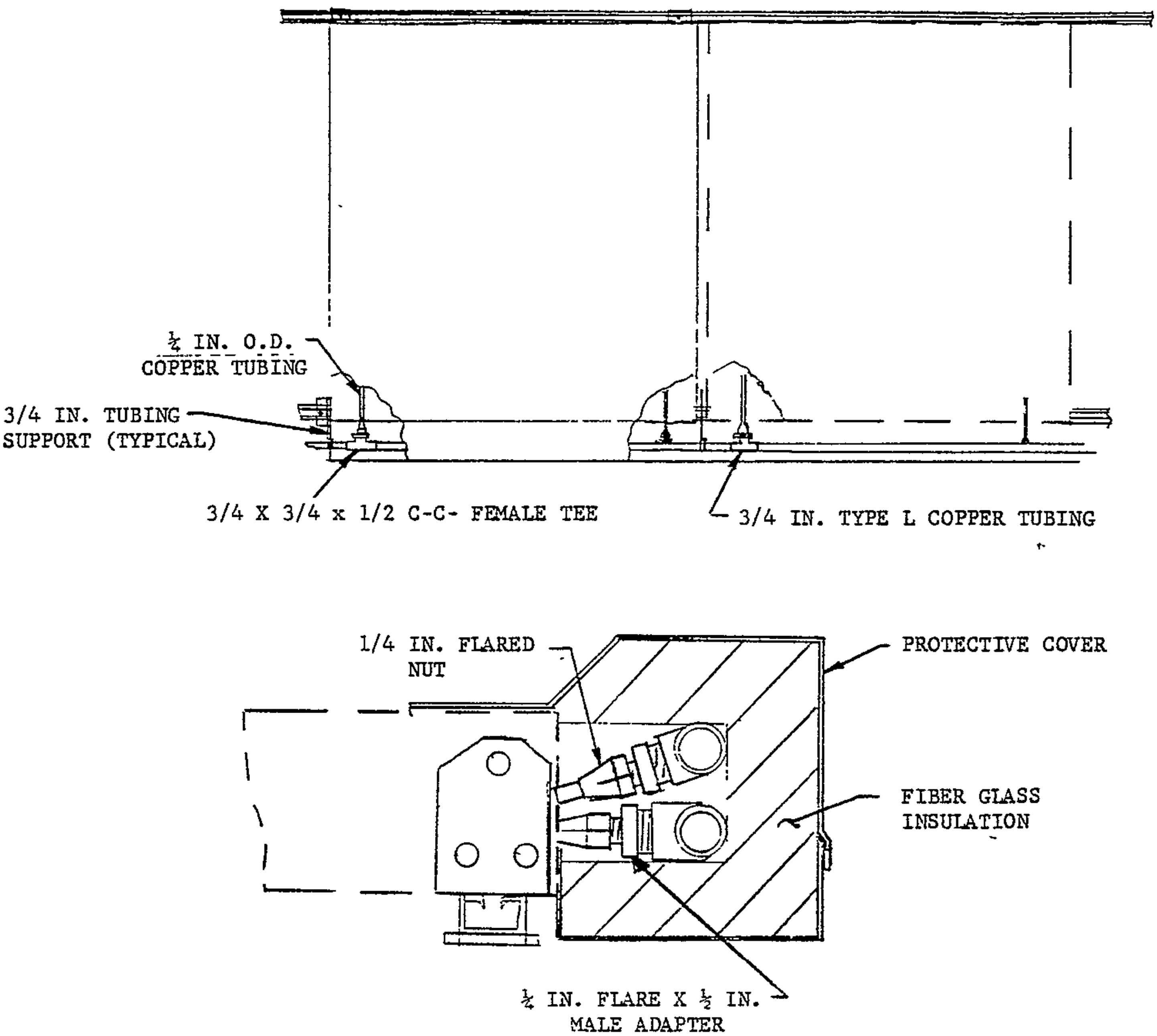


Figure 2.3-1. Collector Interconnecting Manifold

The insulation is a standard fiber glass duct insulation. A typical brand is the Johns-Mansville 800 series spin-glas. This particular insulation offers excellent thermal resistance, lightweight, minimum volume, long life, and ease of installation. A thickness of two inches for a manifold pipe diameter of 0.875 inch is needed to keep heat losses to less than 10% of the daily energy collected.

The manifold configuration is a simple covered manifold. Prefabricated manifolds in lengths of 4 feet and 8 feet will be offered. It is anticipated that the selected diameter of 3/4 inch will be acceptable for most array assemblies.

A collector mounting design has been completed for residential applications. The selected design is insensitive to attic accessibility, or roof slope. Figure 2.3-2 shows an artist concept of the mounting design. Standard slotted unistrut channel will be affixed to the roof. The channel will be secured every 32 inches with standard lag bolts that top into the roof rafters. A 1/4 inch thick neoprene spacer will be installed between the outer roof surface and the bottom of the channel. This spacer will elevate the channel off of the roof and act as a vibration isolator and/or dampener for the collectors. Roof cement will also be applied to the lag bolt to add water proofing. Simple angle brackets will then bolt to the channel and to the collector corner mounting points. Standard aluminum flashing will be installed around the collector array perimeter to channel rain around the array and prevent snow and other material from blowing under the collectors.

2.3.1.1.3 Collector Primary Loop

A Thermacore, Inc. heat transfer specialist was brought in as a consultant for the primary loop primarily to review the loop configuration for feasibility, overall performance, and component function. As a result of its investigations, Thermacore

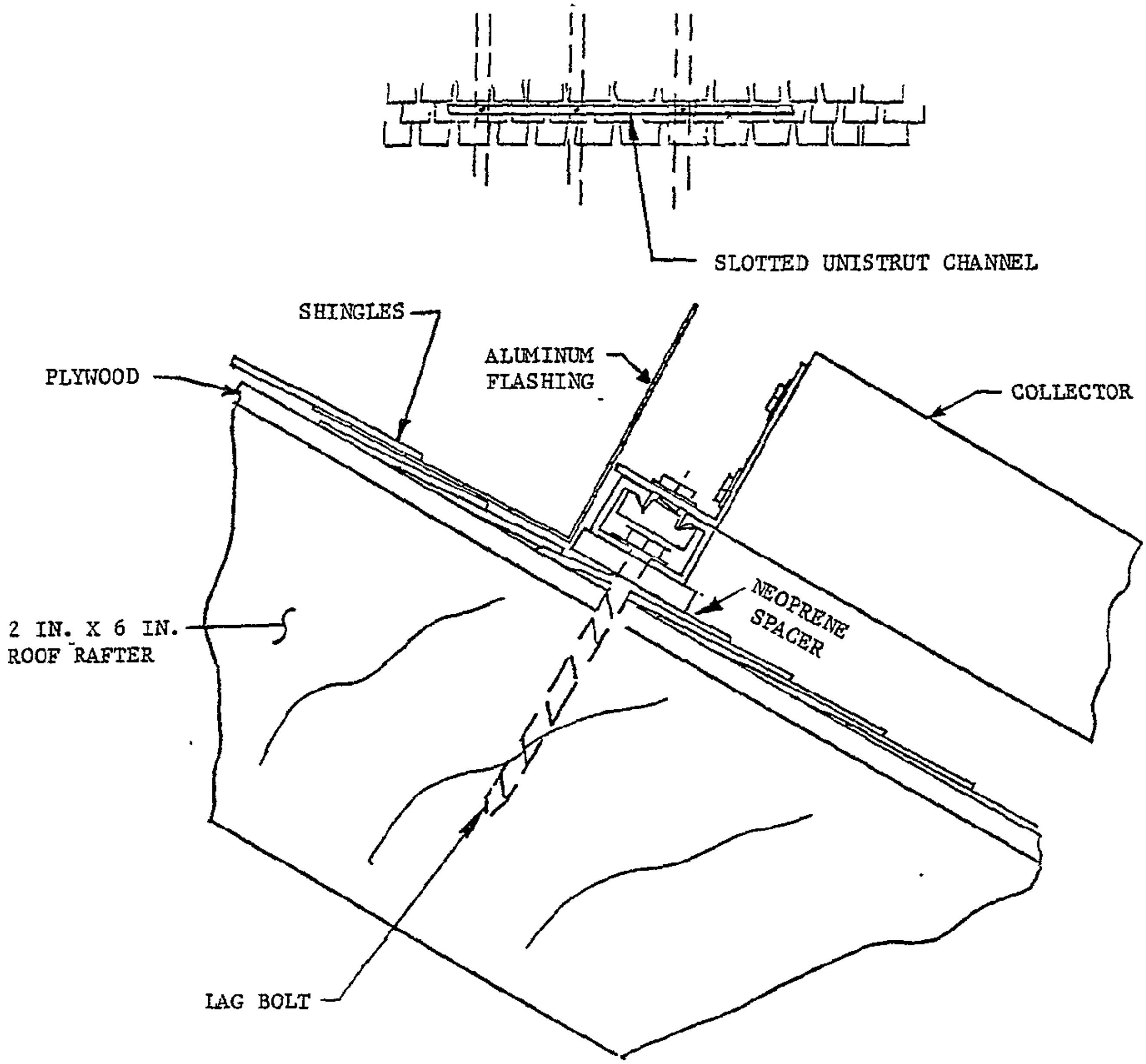


Figure 2.3-2. Collector Residential Mounting Concept

has recommended the following changes:

1. Provide a pump lockout to prevent it from restarting after it had shut down and the collectors reached stagnation temperatures.
2. Include a vapor condensor for hot shutdown.
3. Leave the expansion tank uninsulated (this requires installing an air separator in the loop as opposed to cycling the working fluid through the tank).
4. Eliminate the positive vent since any all-copper system should not generate H_2. However, incorporate a trap for analysis purposes on initial installations.
5. Consider a positive temperature control for overtemperature conditions on large installations.

Figure 2.3-3 shows the present loop configuration without the positive temperature control which incorporates Thermacore's recommendations. The function of each component is as follows:

1. Pump - circulate the fluid
2. VV2 - solenoid valve with time delay. Opens when pump is not operating and closes at some specified time after pump operates.
3. Expansion tank - storage tank for liquid inventory when collectors are drained
4. S - safety valve to prevent overpressure
5. Vapor Condenser - a cold area that reduces partial pressure of working fluid vapor in the hot shutdown condition.
6. Air Separator - Permit flow-through expansion tank only until level of fluid on expansion tank reaches operating water line.
7. Gas Trap - collection point for analysis of gas generated in the system.

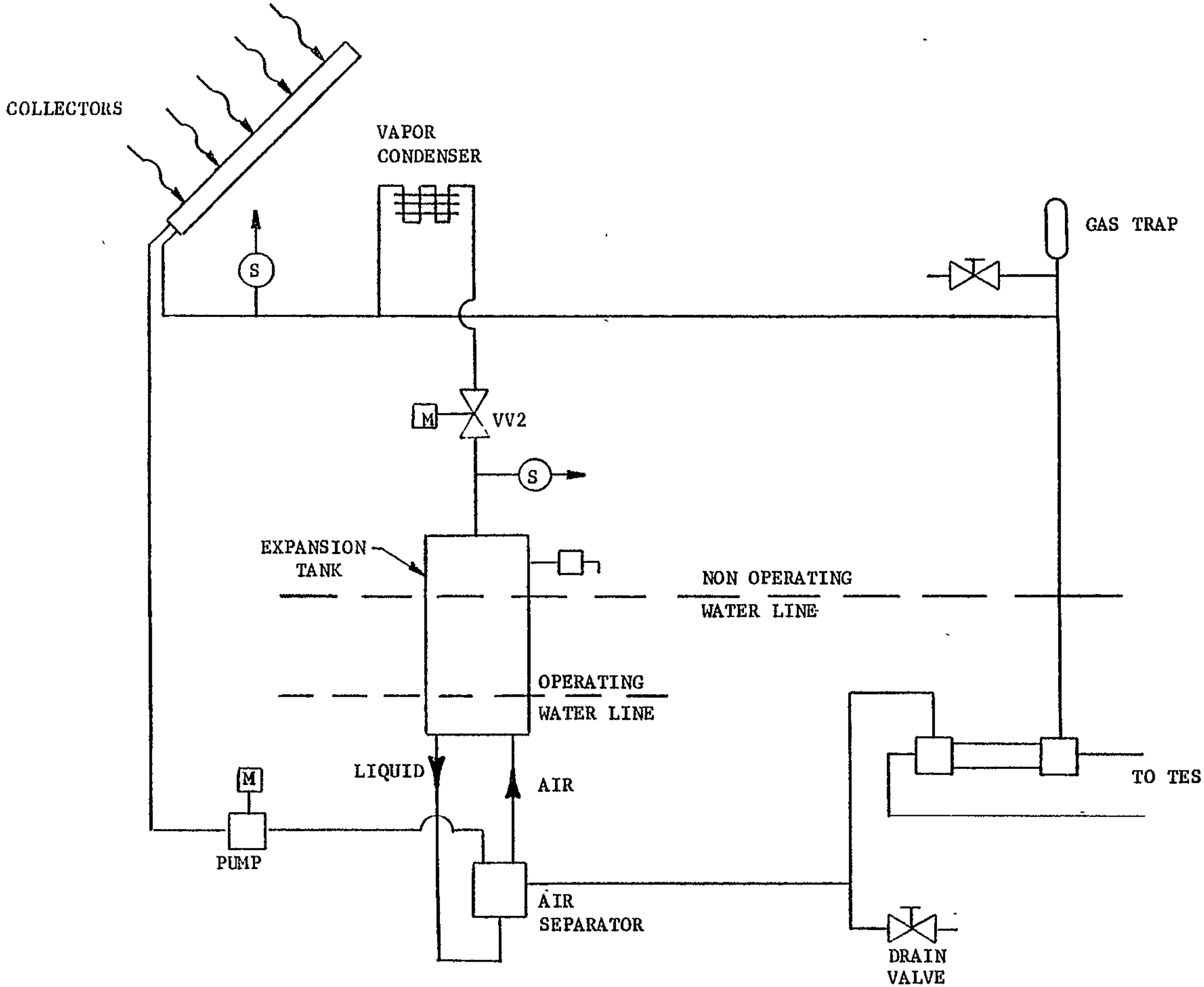


Figure 2.3-3. Present Collector Primary Loop Configuration

It was recommended to use positive temperature control for large systems because of the following:

1. Reliability is inherently higher
2. An active temperature control would allow the system to come back on at any time.

On large systems, the energy consumed to "dump" energy is low and the primary loop for commercial systems will include a positive temperature control. Analyses are presently in progress to see what the penalty would be for smaller systems.

Continued investigation of Prestone II temperature capabilities has not revealed any problems. The inhibitors in Prestone II appear to be effective after short exposures at stagnation temperatures.

2.3.1.2 Energy Storage

Specification 261A2250, Thermal Energy Storage Tanks, issued previously, was revised and expanded to cover the full range of Heating and Heating and Cooling "building block" system sizes. Part numbers were assigned to each increment in performance requirements corresponding to the system building blocks.

A plan is being developed to establish working relationships with various tank vendors whereby, through a system of standard sizing, multiple-use concepts, the total number of different fabricated parts can be reduced. Through this approach, it is anticipated that a low-cost high volume production process can be introduced which can also reduce stocking cost factors.

Specification 261A2868, Expansion Tank, Thermal Energy Storage, has been completed and is being reviewed prior to issuance.

2.3.1.3 Space Heating/Cooling

Specification 261A2859, Air Handlers and 261A2861, Hydronic Coils, have been prepared in the full "building Block" range format as discussed in paragraph 2.3.1.2 and are currently in the review cycle.

2.3.1.4 Auxiliary Energy Subsystem

No significant activity during the reporting period.

2.3.1.5 Hot Water Subsystem

Design evaluation studies have been initiated and specification preparation is currently in process. See also paragraph 2.3.1.7.

2.3.1.6 Energy Transport Subsystem

Specification 261A2852, Collector Pumps, and 261A2853, Energy Transport Pumps, issued previously, have been revised and expanded to incorporate the full range of "bulding block" system sizes as discussed in paragraph 2.3.1.2. Specifications for the collector energy heat exchanger and for mixing, diverting and thermostatic valves are in process.

2.3.1.7 Combined-Function Components

Specifications 261A2855, Combined-Function Tank for thermal energy transfer and storage, and 261A2860, Combined-Function Heat Exchanger for Collector, Storage and DHW, were prepared and issued. These specifications define candidate combined-function items which may replace conventional components to effect system cost savings through elimination of separate procurements, installation, and stocking. Initial vendor contacts to establish sources are in progress.

Specification 261A2867, Auxiliary Hydronic and DHW Heater, has been prepared and is in the final review cycle, prior to being issued.

2.3.1.8 Controls Subsystem (WBS 1.2.2.1.7)

2.3.1.8.1 System Design

The system design has changed in the last quarter for Heating Single Family resulting in a simplification of the controls design. Figure 2.2-1 shows the system schematic for Heating Single Family. A new fluid loop is indicated between the collector loop heat exchanger (HX1) and the thermal storage tank (TES). The new design eliminates the options of direct solar heating and solar boost described in the First Quarterly Report.

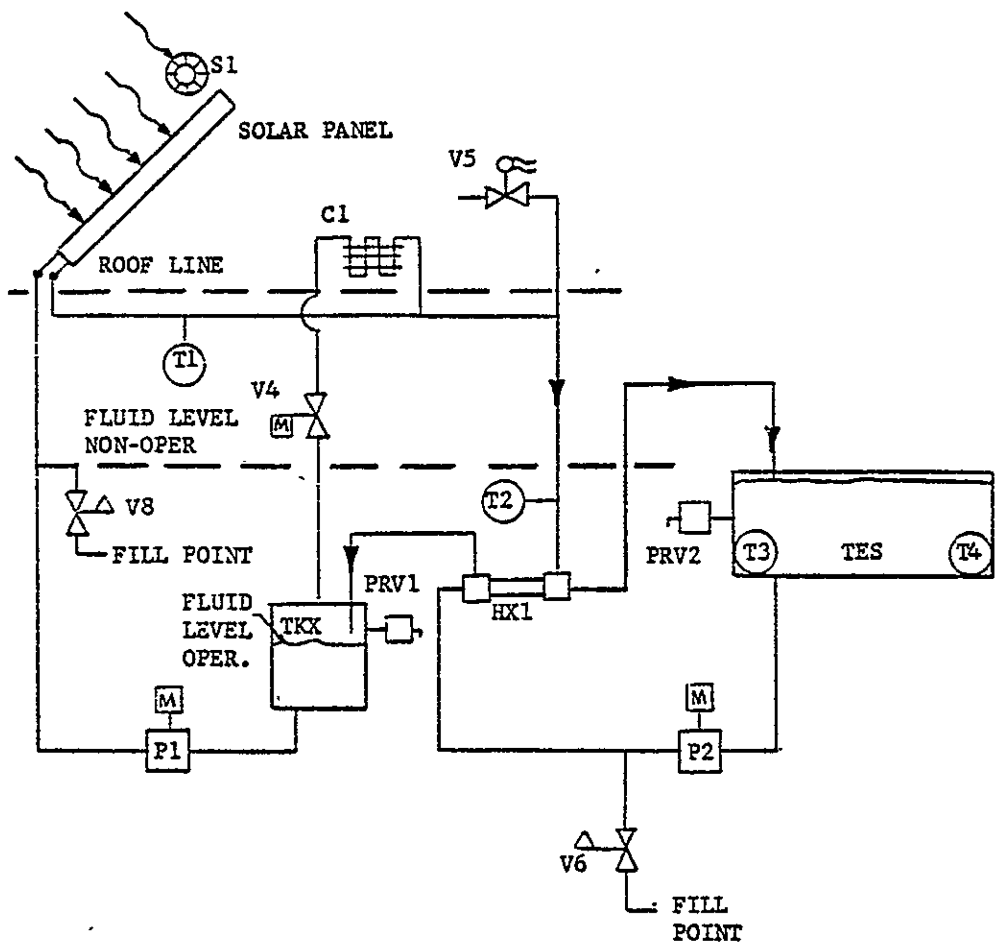
Figures 2.3-4 through 2.3-6 show the major operating modes for Heating Single Family, which are:

1. Solar collection and storage
2. Heating from storage
3. Storage boost heating

Included on each diagram is a list of operating conditions that satisfy the mode shown (i.e. S1-Yes, P1-On, etc.).

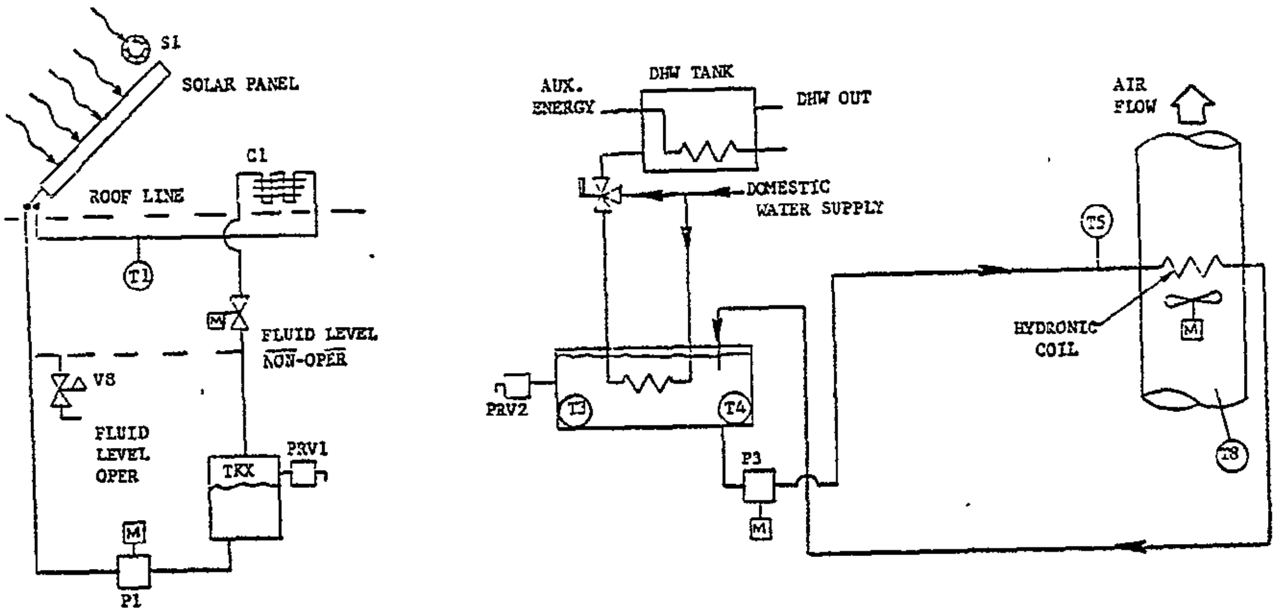
The elimination of the direct solar option means that, as mentioned at the Heating and Cooling PDR, the collection/storage configuration is presently identical for all Heating and Heating and Cooling Systems. Recently, reviewers of the collector subsystem have recommended evaluation of a positive temperature control to limit collector fluid temperatures in the 280°F region in large collector fields. The impact of this configuration change (heat dump) on the controls subsystem is under analysis, but has not been integrated into the system or controls design.

The Heating Multi Family and Heating Commercial Systems have the same system design and control modes as reported in the First Quarterly Report.



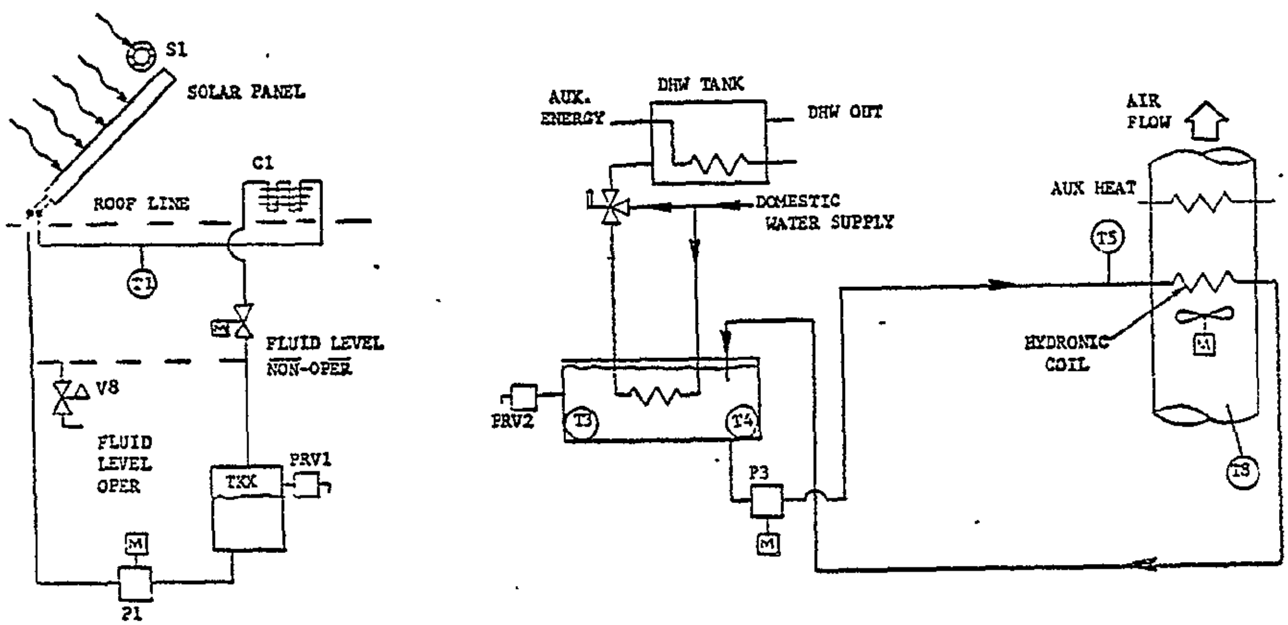
COLLECTION/STORAGE CONDITIONS								
S1	T1	T2	T3	T4	P1	P2	V4	V5
ON	280°	20°	20°	250°	ON	ON	CLOSED	CLOSED

Figure 2.3-4. Solar Storage (HCSF)



S1	P1	P2	P3	T2	T3	T8	AUX. HEAT
NO	OFF	OFF	ON	NA	$> 95^{\circ}$	1st STAGE	OFF

Figure 2.3-5. Heating from Storage (HSF)



S1	P1	P2	P3	T2	T3	T8	AUX HEAT
NO	OFF	OFF	ON	NA	$> 95^{\circ}$	2nd STAGE	ON

Figure 2.3-6. Storage Boost Heating (HSF)

2.3.1.8.2 Component Development

2.3.1.8.2.1 Sensors-Three areas of sensor development have been undertaken in this time period; namely, analog temperature sensors, thermal switches, and solar integrator.

The analog temperature sensor is a nickel-wire RTD. A specification has been written describing the electrical, environmental and packaging aspects needed to use this sensor in the fluid loops and storage tanks of the Heating and Heating and Cooling systems. A request for quotation has been released and two companies have offered samples for evaluation.

The thermal switch development involves a specification which bridges the gap between standard bimetal switches and the packaging and environmental requirements of the Heating and Heating and Cooling Systems. A Request for Quotation has been released to various thermal switch manufacturers.

The solar integrator is a device which measures solar energy over a time period and utilizes decision logic to operate the collector loop pump. The device consists of a rain-tight package which houses a printed circuit board. A silicon photodiode with appropriate spectral and angular response is mounted on the outside of the package to measure insolation. A power loss circuit internal to the logic operates with a "darkness" threshold (measured by the photodiode) to lockout collector loop operation under mid-day power loss (high stagnation temperatures in the collector) conditions.

This package has been breadboarded and is currently on test. In-house printed circuit board and packaging designs are nearing completion. A preliminary specification is written and soon will be released to electronic packaging vendors for quotation.

2.3.1.8.2.2 System Logic Design

Commonality has been achieved in the design of a logic board for the heating systems. A breadboard has been built and bench tested of a logic design which can be used for Single Family, Multi-Family and Commercial Heating Systems. Standard logic integrated circuits have been used in the design in place of the Field Programmable Logic Array (discussed in earlier PDR's) due to cost tradeoffs and system design simplification. Selection of Single Family or Multi-Family/commercial operation is obtained by changing position of circuit board-mounted dual-in-line switches. Power interface is obtained through optical couplers which provide a constant gate signal for a power semiconductor (TRIAC).

The design has been released on the logic board. An in-house printed circuit board layout has been started.

2.3.1.8.2.3 Packaging

An in-house packaging layout is nearing completion to house the system logic circuit board, transformer, terminal strips and semiconductor power switches (TRIAC). This package provides NEMA Class 1 protection to the live circuits, heat sinking for the TRIACS, and field installable mounting, conduit and wiring interfaces. A specification is in process for the package and the system logic board. As in the case of the solar integrator, this specification will be released for quotation to electronic packaging manufacturers.

2.3.1.9 <u>Electrical Subsystems</u>

Quarterly Report No. 1 contains top-level electrical diagrams for the three heating only systems and the philosophical approach being followed in designing both the heating and the heating/cooling electrical subsystems. During the first reporting period, top-level diagrams were generated for Single-family, Multi-family, and Commercial

Heating/Cooling Systems. These diagrams were included in the Heating/Cooling PDR package.

The specific hardware chosen to implement these diagrams is dependent on many things. For example, site related data such as component sizes, component locations, and local electrical codes is of major importance when selecting electrical hardware. Figure 2.3-7 is a more detailed top-level diagram of a typical Heating Single-family System. It conveys the level of detail that can and is being accomplished at this point in the program.

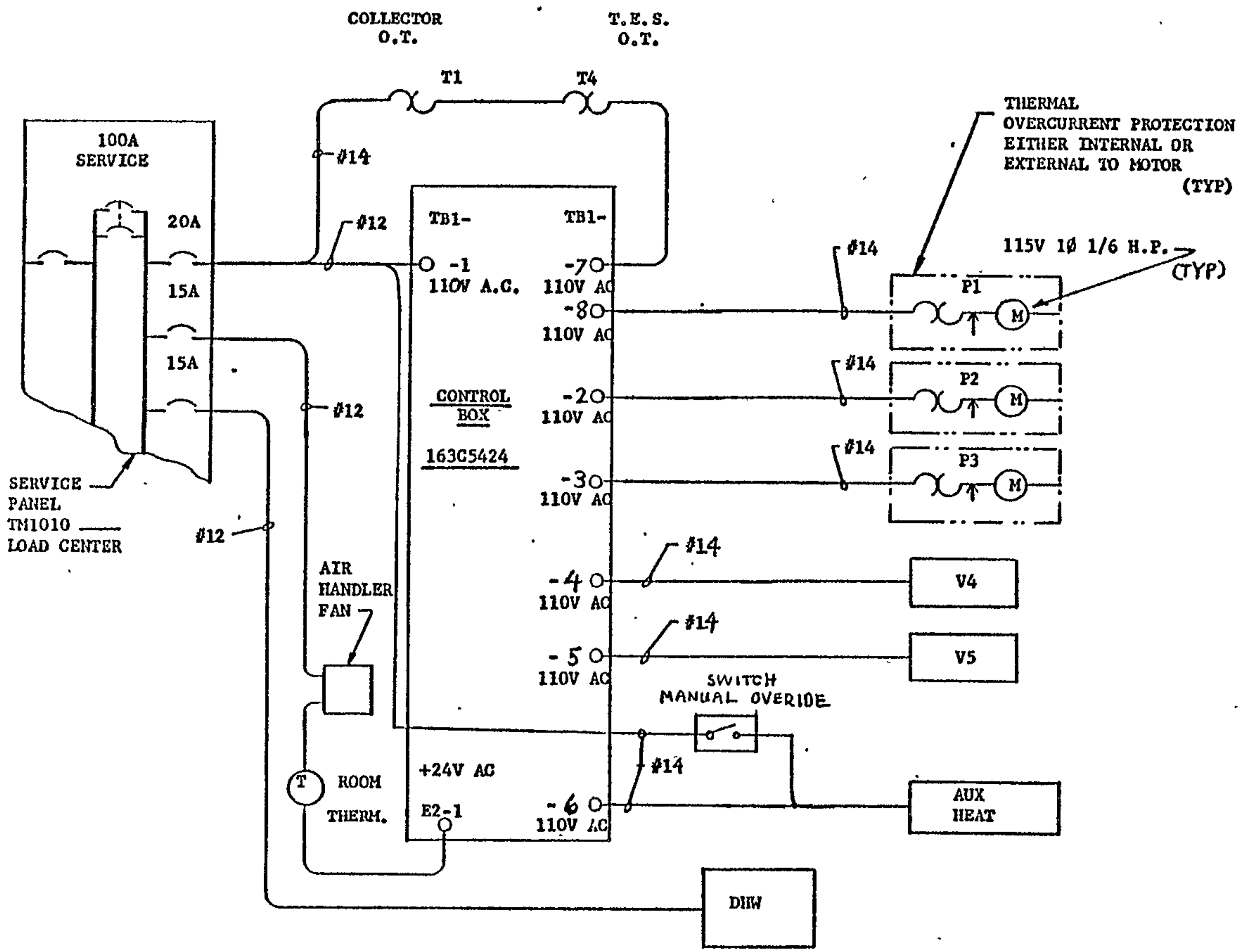


Figure 2.3-7. Detailed Electrical Diagram (HSF System)

2.3.1.10 System Integration

During the reporting period the following significant events took place:

1. The HVAC engineering firm of Walter F. Spiegel, Inc. was sub-contracted to assist in system integration engineering of the 12 deliverable systems plus that of the system test units, among other tasks.
2. All components for the heating-only system-level qualification test unit were identified and their suitability for the system test unit evaluated. As of this writing, purchase orders for the majority of this hardware have been placed.
3. A system schematic for the heating-only system qualification test unit was completed and a system installation drawing is underway.
4. The system test facility design was initiated and is nearing completion. Plans for fabrication of the test facility were formulated.
5. Component specifications were up-dated to include the full range of building block sizes in order to provide units to accomodate the full range of systems from the smallest heating-only single family system to the largest heating and cooling commercial system.

2.3.2 HEATING AND COOLING SYSTEMS (WBS 1.2.2.2)

2.3.2.1 Collectors

Refer to paragraph 2.3.1.1 Development carried out for heating system applies.

2.3.2.2 Energy Storage Subsystem

Refer to paragraph 2.3.1.2. Development of hot TES applies

2.3.2.3 Space Heating/Cooling Subsystem

Use of the heat pump results in different equipment for heating and cooling systems. Activity just starting.

2.3.2.4 Auxiliary Energy Subsystem

Equipment will be different for heating and cooling systems. Activity just starting.

2.3.2.5 Hot Water Subsystem

Refer to paragraph 2.3.1.5. Heating systems work is applicable.

2.3.2.6 Energy Transport Subsystem

Refer to paragraph 2.3.1.6. Heating system work is applicable.

2.3.2.7 Controls Subsystem

2.3.2.7.1 System Design

The system design and control modes were presented at the Heating and Cooling PDR. Because no substantial changes to these operational modes have occurred since PDR, no discussion is presented here. As in the Heating Systems, the evaluation of a positive temperature control of over-temperature conditions and its effect on system design is underway.

2.3.2.7.2 Component Design

?.3.7.2.2.1 Sensors. The sensor development items for the Heating Systems (see paragraph 2.2.7.2) are also applicable to the Heating and Cooling Systems. No new sensor development is foreseen for these systems.

2.3.7.2.2.2 System Logic Board and Packaging. No breadboarding, logic design, or packag- -g design for the Heating and Cooling Systems has been done to date. However, the circuit decisions, packaging layout, and power interface (see paragraph 2.2.7.2) for the Heating Systems shall serve as a baseline for the hardware approach in the Heating and Cooling Systems.

2.3.2.8 Electrical Subsystem

Refer to paragraph 2.3.1.9. Approach allows growth for cooling systems.

2.3.2.9 System Integration

Refer to paragraph 2.3.1.10. Activity not started this period.

2.3.2.10 Cooling Subsystem (WBS 1.2.2.2.11)

The cooling subsystems consist of either 3-ton solar driven heat pumps or 10-ton solar driven air conditioners and their related equipment. Subsystem Cycle 1 hardware design, fabrication, and test activities continued through the reporting period. In addition, Cycle 2 design concepts were initiated during the past Quarter.

2.3.2.10.1 LTR Design State Point Schematics

The state point schematics for both the 3 ton and 10 ton low temperature Rankine (LTR) loops at the design point were presented in Quarterly Report No.1. Cycle 1 LTR hardware is being sized to meet these requirements.

System economic studies showed that a thermal seasonal performance factor of 0.9 for the cooling season was necessary for solar energy to become economically competitive with alternate forms of energy. The focus of our analytical effort this past quarter has been to investigate the performance of various

LTR and heat pump and air conditioner configurations and identify what features are necessary to meet performance goals.

2.3.2.10.1.1 Subsystem Analysis Procedure - Since a major development item for the heating and cooling system is the LTR solar driven engine, a detailed LTR system analysis code was developed to provide performance simulations and to provide the basis for specifying the cycle state points, mass flows, component performance, parasitic power requirements, and power and torque required for the solar driven compressor. The code solves for a steady state system condition using fixed boundary conditions of ambient temperature and solar hot water temperature into the vapor generator. The performance of the heat pumps and air conditioners is determined using analysis codes developed and used by GE-CR&D. This code functions on the same level as the LTR code, i.e. detailed component models are used which utilize actual hardware performance characteristics. This code defines the refrigerant cycle state points, component performance, parasitic power requirements and the power demands to be placed on the LTR or electric motor. The LTR and HP/AC combinations are separate systems joined together with a common expander/compressor shaft. For this reason, it is appropriate to consider the performance of the combined LTR and the HP/AC as it varies with speed as well as with environmental conditions, i.e. solar input and ambient conditions. Under fixed solar and ambient conditions, the steady state matched operation will occur at a speed where power delivered by the LTR equals the power required by the solar driven compressor. As the solar fluid inlet temperature varies, the power delivered by the LTR will vary and the combined system will reach a new steady state speed point. As the solar fluid temperature drops, so does the matched speed, until eventually the LTR cannot meet the solar driven compressor requirements and a no-match condition results. By repeating this process for different ambient conditions, a mapping can be made of steady state matched operation. Thus, for a given ambient temperature and solar fluid inlet temperature, complete system operating conditions and performance parameters can be specified.

Once the operating range is known, it is possible to determine where the system will operate. However, it may not be desirable to operate under certain conditions. By knowing how certain conditions vary, such as matched speed or vapor generator exit quality, the control system can then be designed to maintain these parameters within acceptable limits.

This procedure of mapping LTR and HP/AC performance, and matching them to determine the steady state operating footprints, has been utilized to investigate system operation and energy effectiveness.

2.3.2.10.1.2 Configurations Analyzed and Results. Table 2.3-2 outlines the LTR and HP/AC configurations that were analyzed. Maps were generated only for the cooling mode since solar driven heating had been shown not to be cost effective. Thus far, 11 different configurations have been investigated. They involve combinations of:

1. Size (3 ton and 10 ton)
2. LTR condenser type (air cooled and water cooled)
3. HP evaporator (air or chilled water)
4. Mode of operation (matched or motor boost) - Matched operation was described in paragraph 2.3.2.10.1.1, i.e. the expander/compressor speed adjusts until an energy balance is achieved between the LTR and HP/AC

Motor boost operation is as follows: Expander, compressor, and motor are mounted on a common shaft, and the expander unloads the motor as power is delivered to the expander. This mode runs at close to a constant speed. Different expander/compressor speed combinations were investigated to determine where these two components match for best efficiency.

5. Expander and compressor speeds

Also shown in Table 2.3-2 are the calculated thermal COPs at ambient temperatures of 95°F (the design rating point) and 75°F (a lower ambient temperature for cooling). For the cases where chiller operation is considered, the COP's are also a function of chiller temperature. As can be seen certain configurations yield low thermal COP's. Because the performance goal is a system SPF, i.e. cooling seasonal averaged COP of 0.9, only a few of the configurations investigated (9, 10, 11) have

Table 2.3-2. LTR/HP/AC Configurations Analyzed

CONFIGURATION	SIZE TONS	LTR CONDENSER	HP/AC EVAPORATOR	MODE	EXPANDER / COMPRESSOR SPEED ~ RPM	CALCULATED THERMAL COP 95°F	CALCULATED THERMAL COP 75°F
1	3	AIR	DX	MATCHED	1800/1800	0.45	0.50
2	3	AIR	DX	MOTOR BOOST	1800/1800	0.45 (90%)	0.50 (100%)
3	10	WATER	CHILLER	MATCHED	1800/1800	0.28 @ 40°F 0.37 @ 55°F	0.37 @ 40°F 0.60 @ 55°F
4	10	WATER	CHILLER	MOTOR BOOST	1800/1800	SAME AS 3	SAME AS 3
5	10	WATER	DX	MATCHED	1800/1800	0.44	0.52
6	3	AIR	CHILLER	MATCHED	1800/1800	0.28 @ 40°F 0.33 @ 55°F	0.31 @ 40°F 0.35 @ 55°F
7	3	WATER	DX	MATCHED	1800/1800	0.52	0.58
8	10	AIR	CHILLER	MATCHED	1800/1800	< 0.3	< 0.3
9	3	AIR	DX	MATCHED	900/900	0.50	0.75
10	3	AIR	DX	MATCHED	900/450	0.60	0.75
11	3	WATER	DX	MATCHED	900/900	0.64	0.98

the potential of attaining this goal. While the performance of configuration 10 is comparable to that of 9, the fact that it is not a direct expander/compressor drive system makes it less desirable as a product.

The configurations that show the highest potential for meeting the performance goals are configurations 9 and 11. Configuration 9 is a 3 ton, air cooled LTR, DX air conditioner. Shown in Figure 2.3-8 is a COP operating map for this configuration. Also shown in this curve is the upper limit on performance for this machine. This limit represents the performance for a system where:

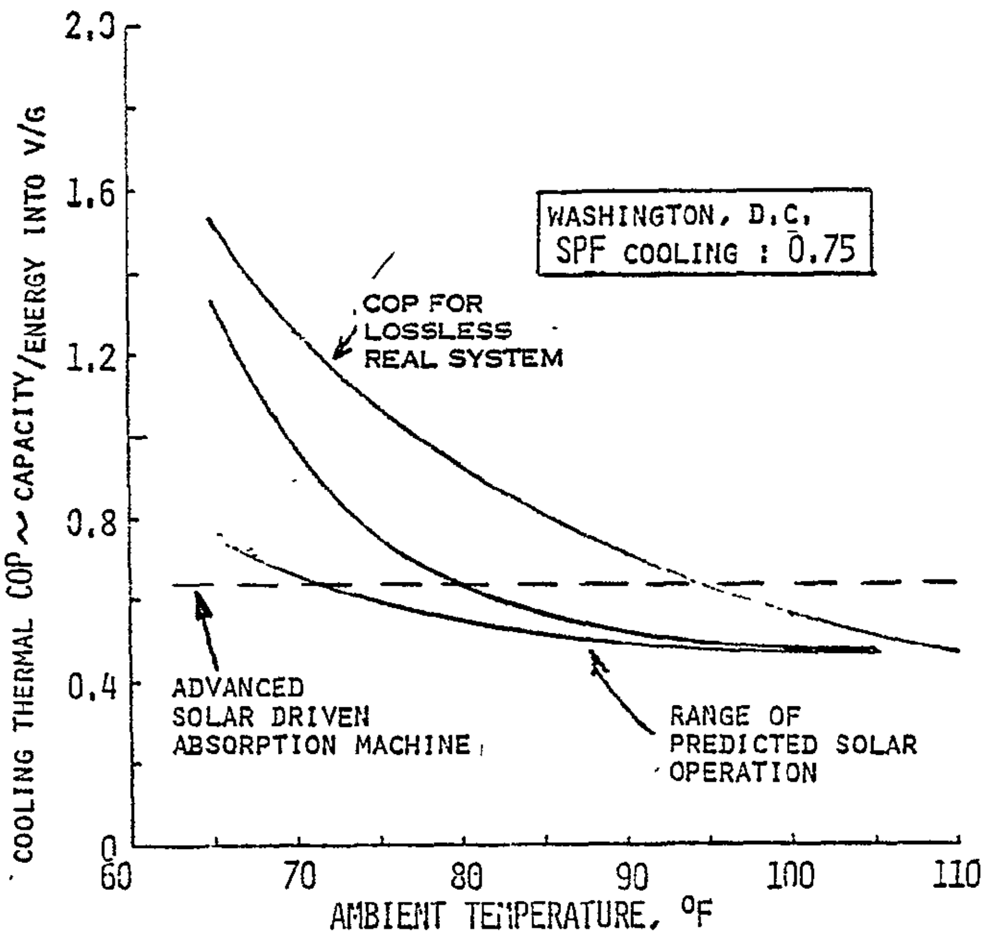


Figure 2.3-8. - Air Cooled LTR Performance, Configuration 9

1. The expander and compressor have been matched perfectly in speed at their maximum efficiencies

2. Heat exchangers are at their limit of effectiveness, i.e. they are oversized but not infinite

3. There are no pressure drops or thermal losses in the system.

By maximizing and optimally matching all the components in both the LTR and HP/AC, the performance of the solar driven subsystem will approach this limit. Also shown, is the COP characteristic of an advanced solar driven absorption machine. While configuration 9 will perform better than the absorption machine, it does not yet yield an SPF consistent with the established goal.

Figure 2.3-9 presents the COP operating map for configuration 11, a 3-ton DX air conditioner utilizing a water cooled LTR condenser in liew of the air cooled condenser. Also shown is the upper limit on performance and the performance of the advanced solar driven absorption machine. As can be seen not only does this configuration surpass configuration 9 and the absorption machine, but it achieves the performance goals that have been set.

2.3.2.10.2 Expander Design

The basic philosophy with respect to expander design goals has not changed since the last reporting period.

The main objective of the first-cycle 10 ton expander is to prove scale-up techniques. Secondary objectives are to evaluate various bearing and shaft seal configurations as outlined in the Preliminary Design Review Package dated 11/1/75.

Objectives of the first cycle 3 ton expander development as outlined in PDR

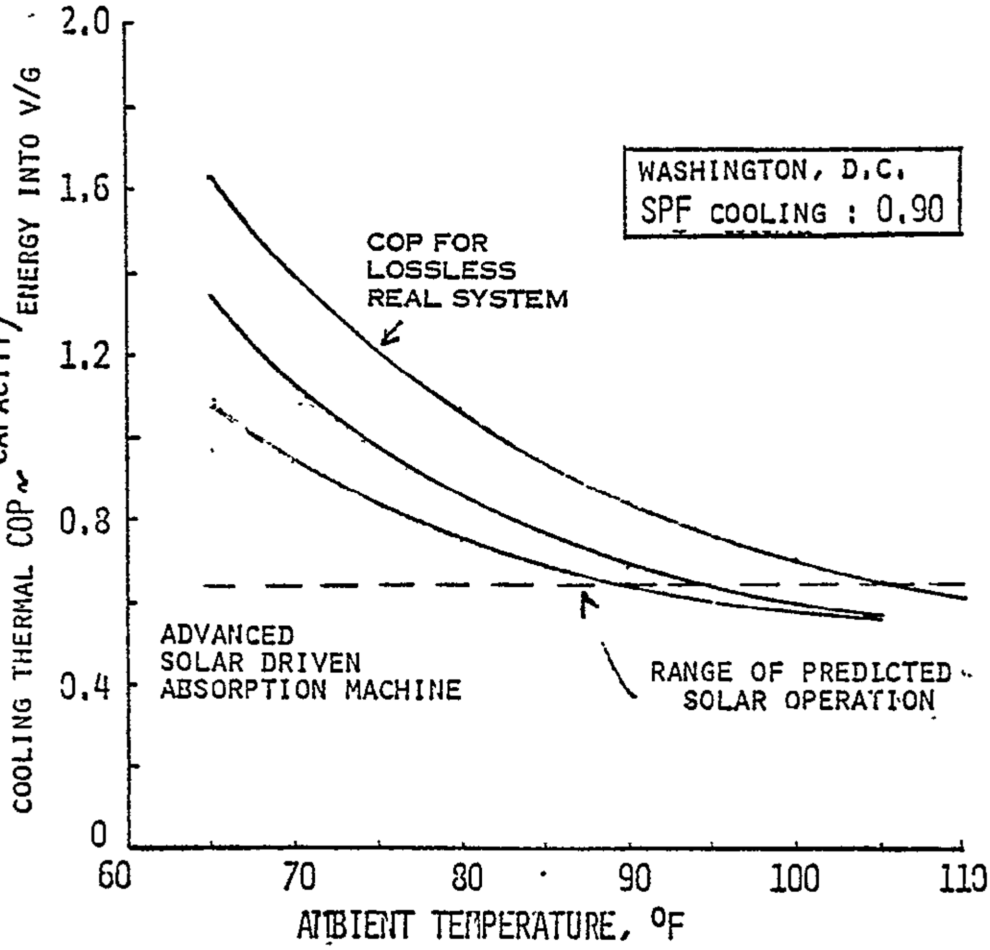


Figure 2.3-9. Water cooled LTR Performance, Configuration 11

package 11/1/76, are to evaluate the following:

1. Vertical mounting configuration
2. Oil lubricated versus grease packed bearings
3. Low cost materials (carbon steel and aluminum)
4. Low cost wear resistant finishes
5. Single versus double shaft seal configurations.

In addition to the aforementioned tasks, two more development activities were added to the scope of Cycle 1 hardware.

The first is the design and fabrication of an eight-vane expander. Previous expanders utilized 10 vanes. Early analytical work predicts higher efficiencies at lower speeds for the eight-vane expander as evidenced by Figure 2.3-10.

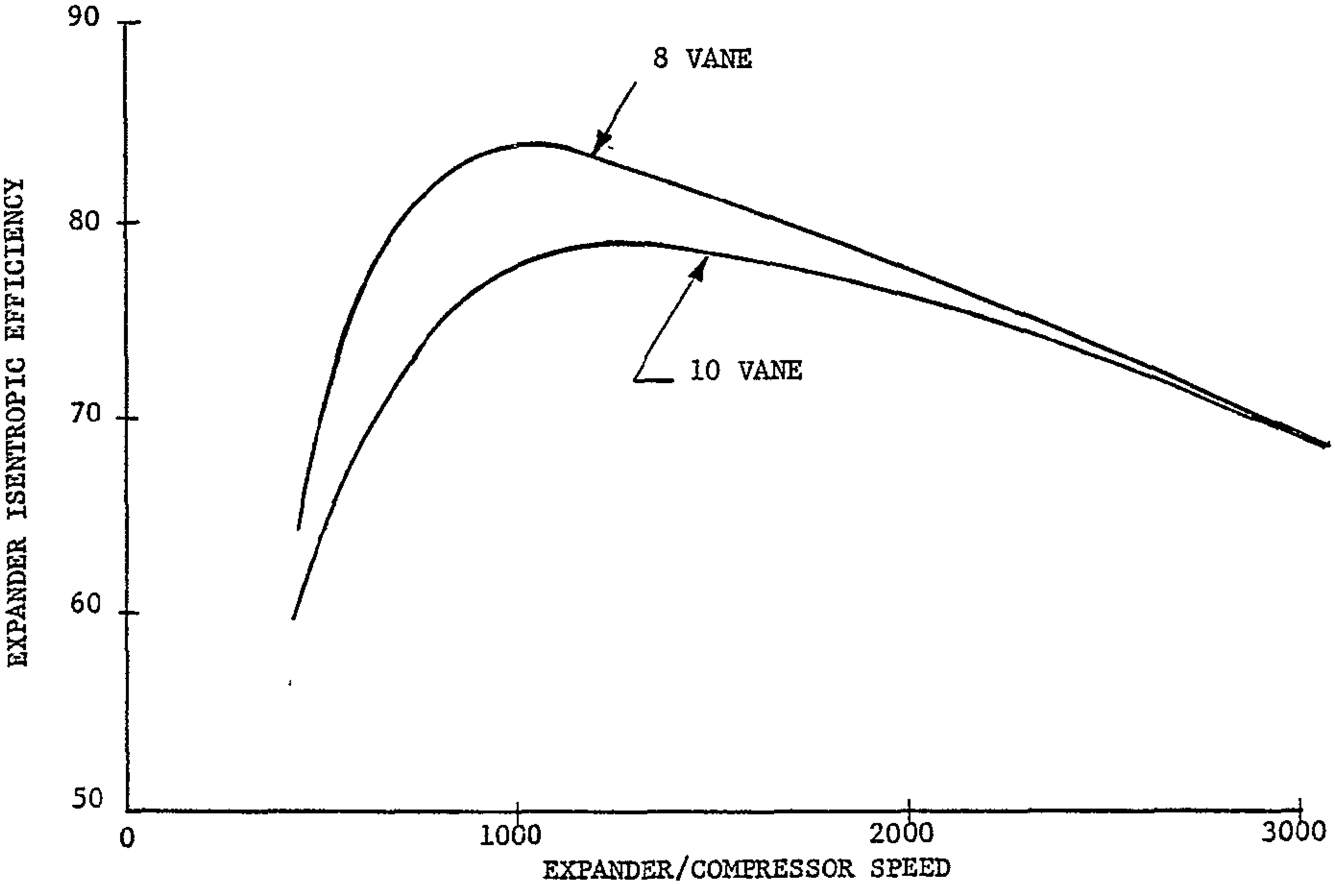


Figure 2.3-10. Efficiency vs. Speed, 3 Ton Expander

The General Electric expander performance computer program was utilized to predict the results as shown on Figure 2.3-10.

Reduced friction, both vane-to-stator and vane-to-rotor-slot, reduced dead volume, and reduced breathing losses were considered in this analysis. Significant hardware savings are also evidenced with the eight vane design. The goal of the aforementioned task is to verify predicted analytical models. Along with the eight vane rotor, the production design techniques illustrated in Figure 2.3-11 will be incorporated in order to obtain early data on manufacturing feasibility and performance variations.

Secondly, analyses have been initiated toward obtaining commonality of major components which comprise the 3 ton and 10 ton expander. The goal is to obtain common diameter expanders which vary in length only.

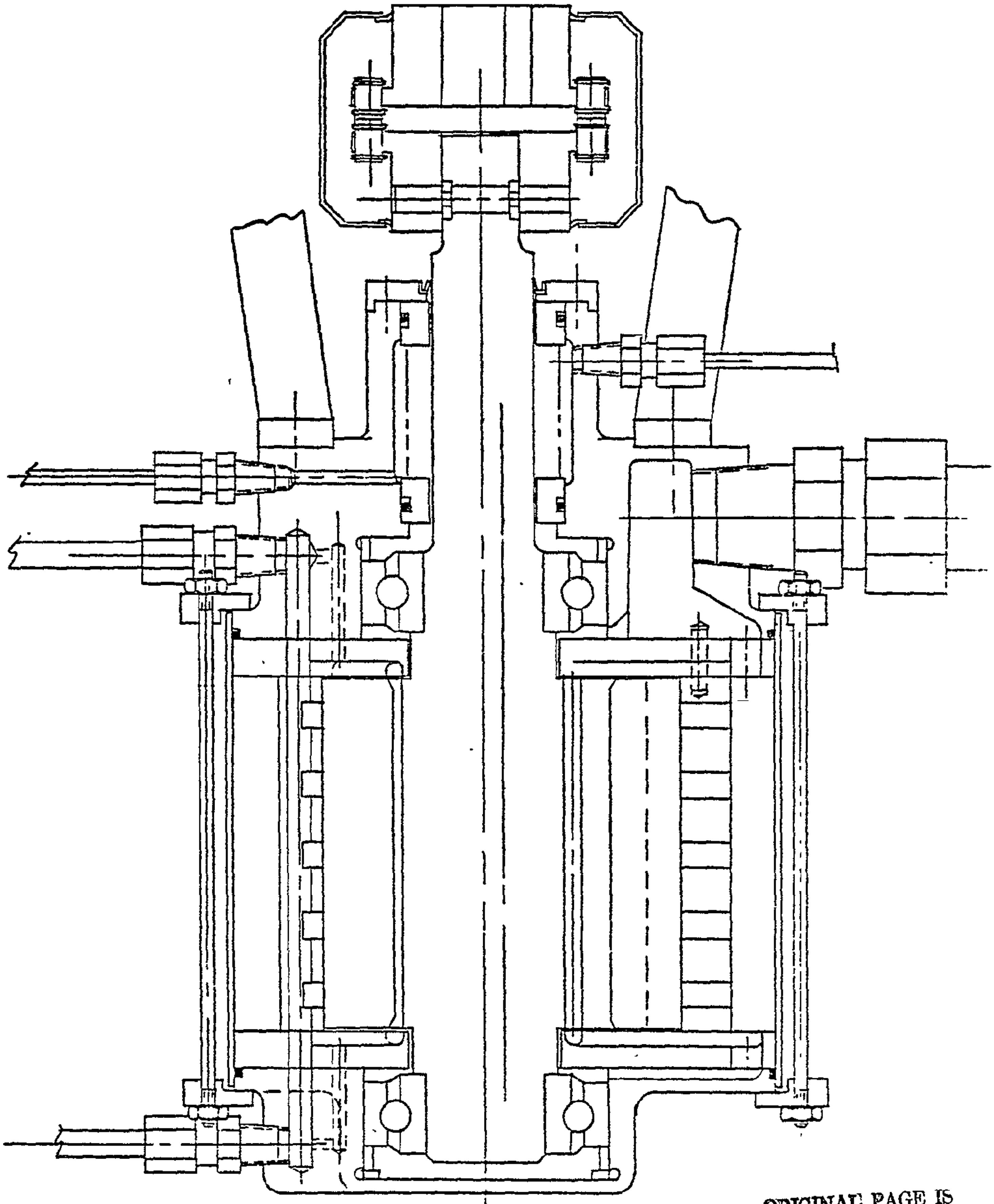


Figure 2.3-11. 3-Ton, 8-Vane Expander Production Design

First cycle (10 vane) 3-ton and 10-ton expanders will be completed and ready for testing in mid-January 1977. The first cycle (8 vane) 3-ton expander is scheduled to be fabricated and ready for testing in early April 1977.

2.3.2.10.2.1 Expander Testing. Detailed test plans are currently being generated. The basic parameters are as follows:

10-Ton

1. Determine operating characteristics:
   a. Efficiency
   b. Output versus RPM
   c. Oil lubricated versus grease packed bearings
   d. Shaft seal
2. Evaluate quality of R-11 vapor delivered to the expander
3. Evaluate running properties of the expander
   a. Temperatures
   b. Pressures
   c. Vibration
   d. Noise
4. Evaluate and confirm and/or modify computer sizing program
5. Evaluate and determine percent of oil in freon required for lubrication of bearings and vanes.

3 Ton

1. Same as 10 ton except with added evaluations listed below:
   a. Expander materials evaluation to test aluminum, low carbon steels and and wear resistant coatings and/or processes

C-2

b. 8 vane versus 10 vane expander

c. Vertical versus horizontal mounted expander.

2.3.2.10.3 Feed Pump

During the past quarter, both 3 ton and 10 ton first cycle feed pumps were released for fabrication. Fabrication and assembly is scheduled to be completed as follows:

3 ton - January 1977

10 ton - February 1977

The first cycle feed pumps are comprised of a double stage pump as described in the PDR package dated 11/1/76. The first stage is centrifugal while the second stage is a positive displacement gerotor type. Figure 2.3-12 illustrates the 3 ton first cycle pump design.

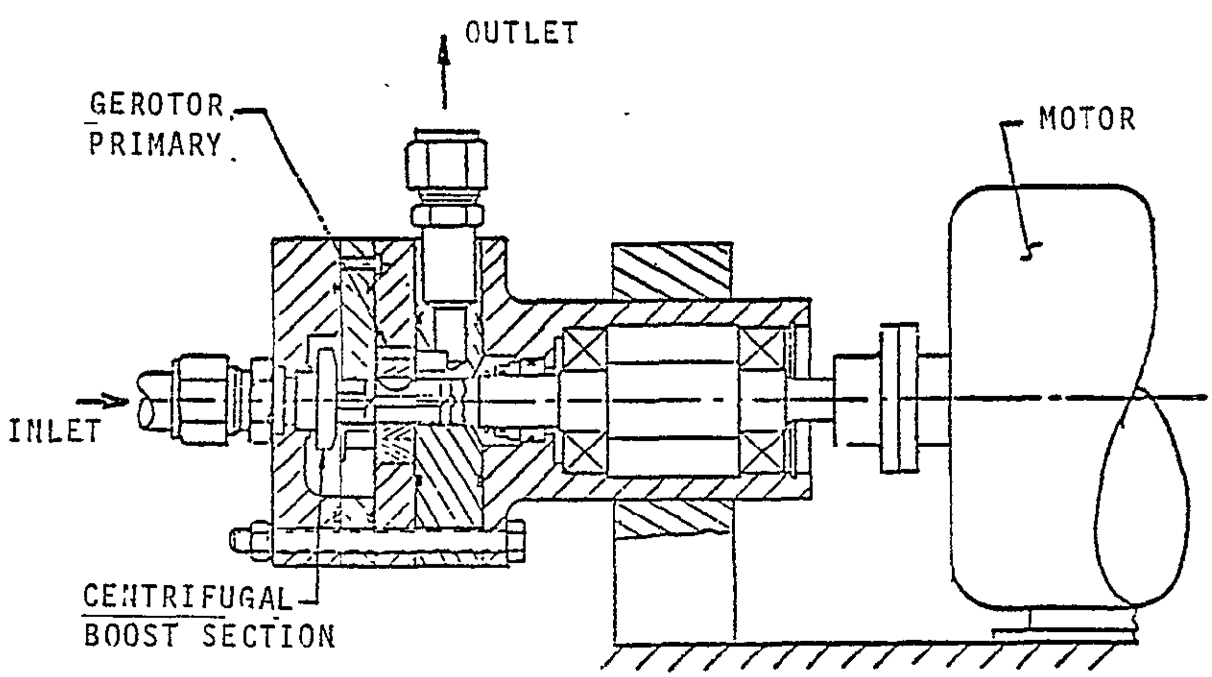


Figure 2.3-12. First-Cycle Positive Displacement Two-Stage Feed Pump

In addition, second cycle pump development tasks have been started. Initially, an in-depth vendor search was conducted in order to determine the availability of pumps which meet our requirements.

Several candidate pumps were located. Currently, these pumps are being procured for evaluation at General Electric. The most promising candidate is a variable volume vane type pump. Table 2.3-3 delineates the technical requirements for both size pumps.

Feed pump test plans have been generated and are concerned with the following:

1. Evaluation of running properties
    a. Temperatures
    b. Pressures
    c. Vibration
    d. Noise
2. Evaluate operating characteristics
    a. Flow versus head
3. Flow versus net positive section head
4. Cavitation versus net positive suction head
5. Material wear properties
6. Volumetric efficiency
7. Overall efficiency
8. Input power requirements

Table 2.3-3. Feed Pump Technical Requirements - Preliminary

	3-Ton	10-Ton
Flow Rate	1.5 gpm	4.5 gpm
Pressure-Out	165 psia	
Net Positive Suction Head (Above liquid vapor pressure)	1 psia	
Inlet Temperature	10 to 120°F	Same
Fluid	Freon - 11 with 4% Zephron Oil	
Motor Power	115 V/60 Hz One-Phase	220V/60 Hz One-Phase
Efficiency, Pump	60% min.	65% min
Pump and Motor	30% min	35% min
Design Life	20,000 hours over 10 years	Same

Configuration - Vertical shaft unit in sealed pump tank with electric motor in Freon vapor above liquid level.

2.3.2.10.4 Vapor Generators

The function of the vapor generator is to utilize the thermal energy of the solar loop to vaporize the R-11 Rankine cycle working fluid.

Cycle 1 design requirements are as shown in Table 2.3-4.

Table Cycle 1 Vapor Generator Requirements

3 Ton	Heat Transfered	83,000 BTU/HR
FLUID	Rankine Loop (R11)	Solar Loop (Corrosion Inhibited Fluid)
T_{in}	127°F	245°F
T_{out}	222°F	235°F
P_{in}	137 PSIA	-
P_{out}	134 PSIA	-
Flow Rate	1125 lb/hr	16 gal/min
10 Ton	**Heat Transfered**	**324,000 BTU/HR**
FLUID	Rankine Loop (R11)	Solar Loop (Corrosion Inhibited Fluid)
T_{in}	110°F	245°F
T_{out}	223°F	235°F
P_{in}	138 PSIA	-
P_{out}	135 PSIA	-
Flow Rate	4184 #/Hr	65 gal/min

Primary considerations for first cycle hardware are:

1. Efficient operation
    a. Minimum package size
    b. Minimum pressure drop
    c. Lowest cost materials
2. Cost Effectivity
3. Compliance with ASME and UL guidelines

Pending test results of first cycle hardware, further improvements in the materials and fabrication techniques area will be incorporated in Cycle 2 hardware.

A tube and shell design was selected for Cycle 1 after an evaluation of plate and fin, tube and tube, pool boiler, and tube and shell candidates. The tradeoff is discussed later in this section.

The first cycle design is shown in Figures 2.3-13 and 2.3-14. Note that the manifolds are bulky and that the Freon-11 manifold is bolted to the shell. This was done on Cycle 1 hardware to facilitate manufacturing and allow for a quick partial disassembly during the test phase. For Cycle 2 the vapor generator could be a completely sealed unit for reduction of size, number of parts, weight and cost.

A matrix of over 50 material choices for the vapor generator was considered. The choice for two components; ferritic steel for the refrigerant tubes, and black steel for the shell, reflect first cycle concerns for component material compatibility and interaction with the subsystem, ease of fabrication, and cost.

The types of heat exchangers that were considered are illustrated in Figure 2.3-15. The plate and fin type exchanger is best applied on heat transfer between gases or a liquid and a gas. It has advantages of a high area to volume

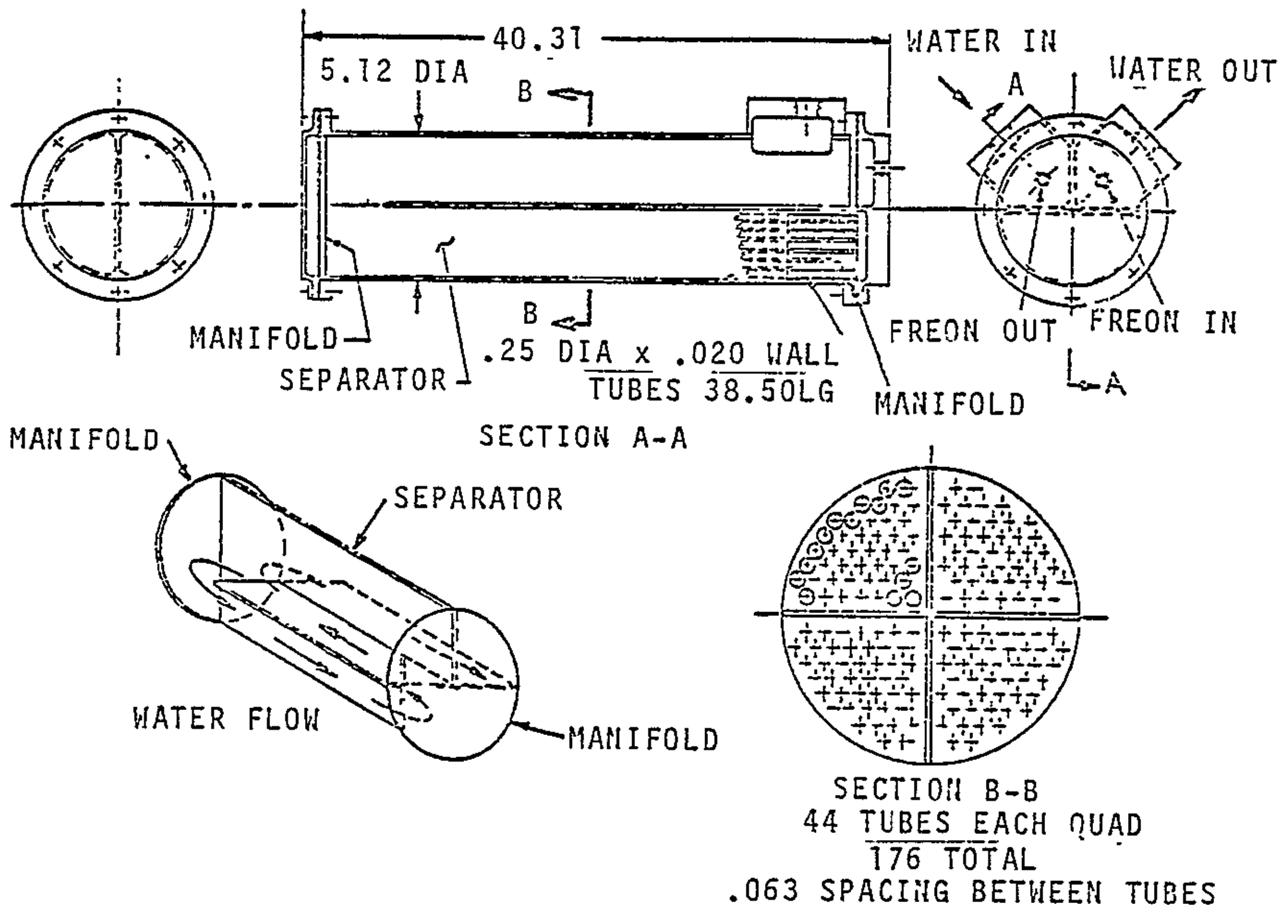


Figure 2.3-13. 3-Ton Vapor Generator (Cycle 1)

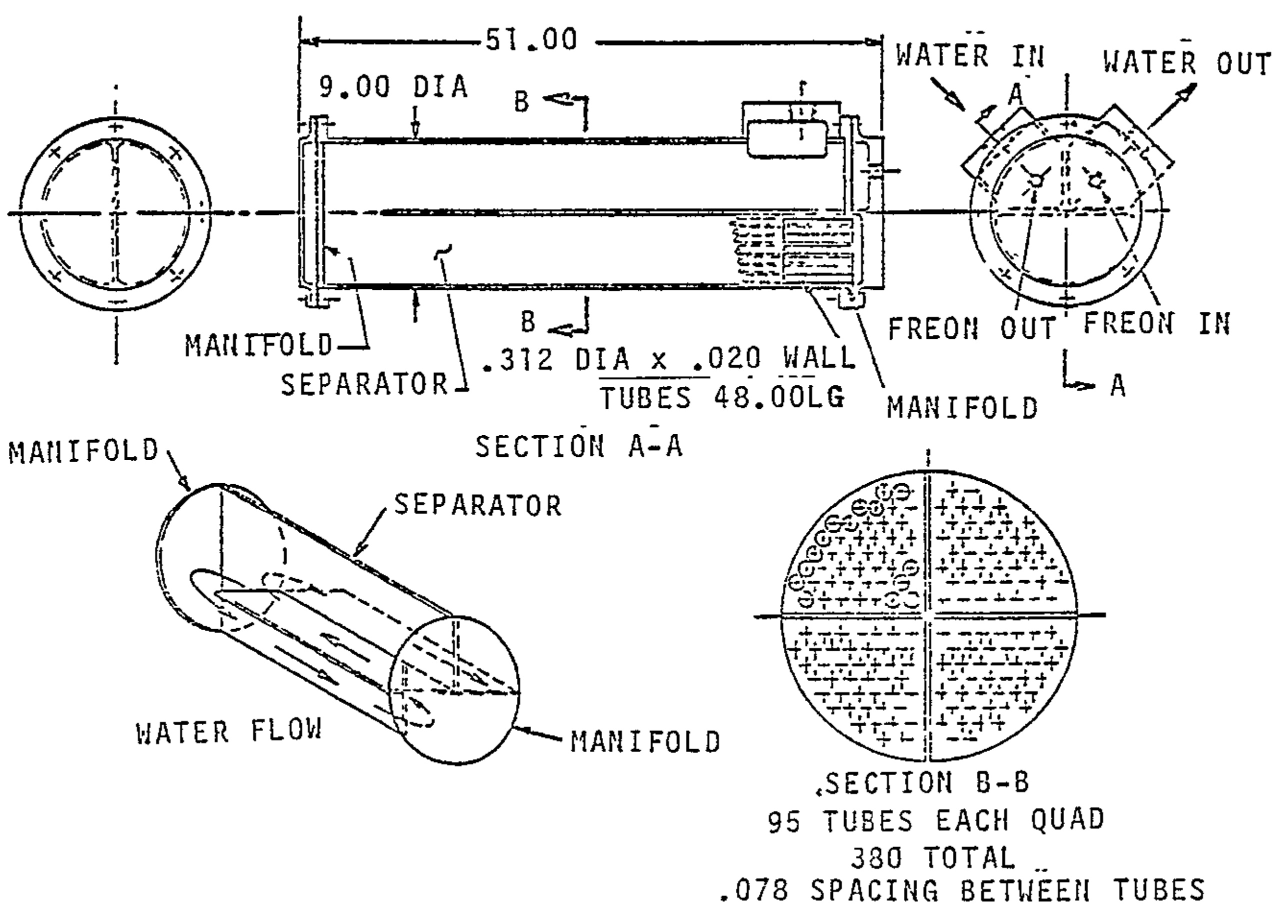


Figure 2.3-14. 10-Ton Vapor Generator (Cycle 1)

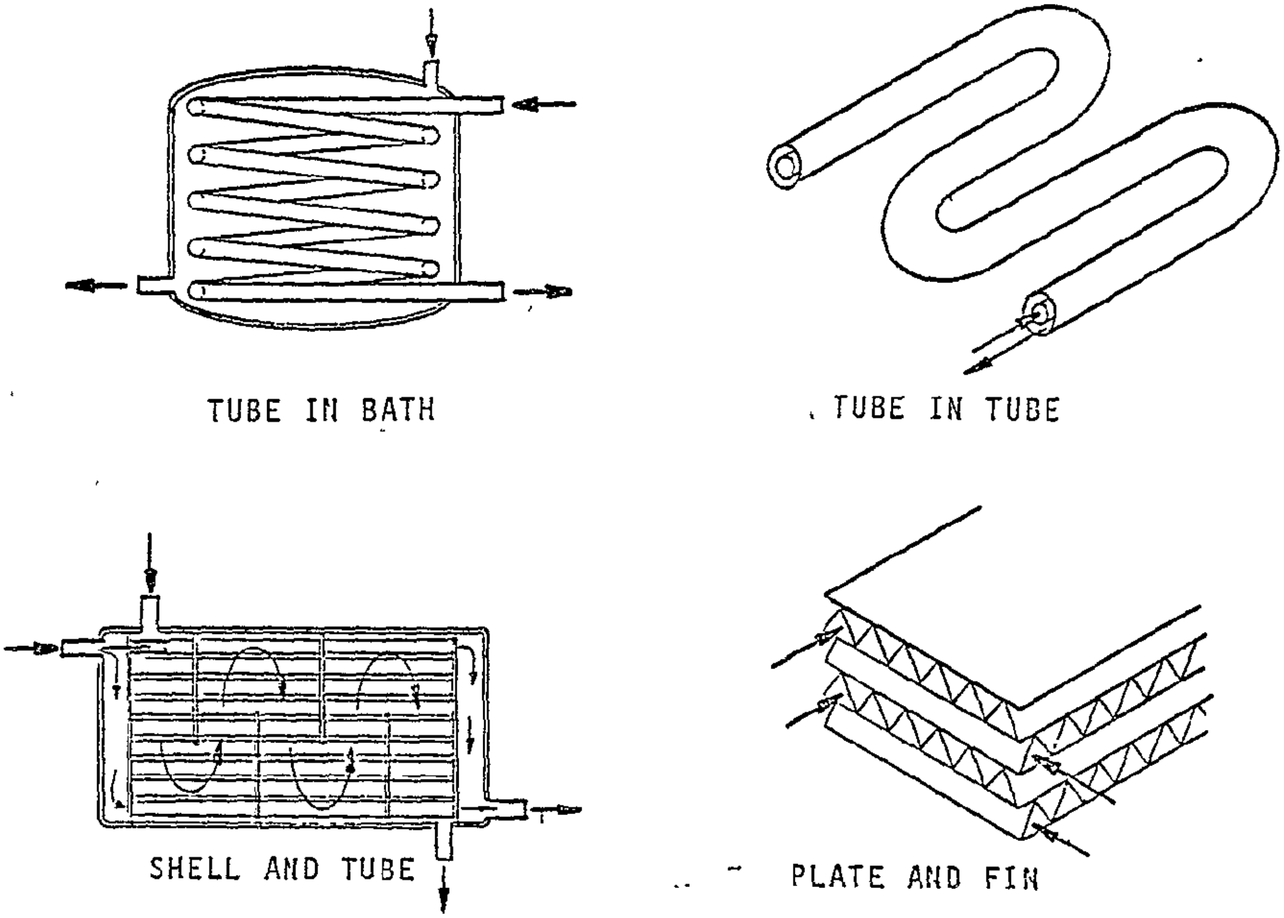


Figure 2.3-15. Vapor Generator Concepts

ratio and ease of fabrication, but in liquid-to-liquid heat transfer application, it is leak prone due to high pressures, and makes manifold design difficult.

The tube-in-tube exchanger is a very efficient heat transfer unit. Its construction is simple for straight lengths. For a large area requirement, however, tube length gets to be quite large, presenting design difficulties for compactness.

More important, however, is the disadvantage of large pressure losses in the two phase regime due to large vapor velocities and tube length.

The pool boiler could satisfy the heat exchanger requirement. It has the added advantage of being quite simple. Its disadvantages include the need for extremely large surface areas to compensate for a poor Freon-11 film coefficient, thus requiring a large refrigerant inventory. The lubricant entrained in the refrigerant forms a layer at the pool surface, contributing negative viscous effects on the film coefficient and creating a problem for effecting its removal for expander and compressor lubrication.

The shell and tube heat exchanger effectively satisfies the heat transfer requirement, employing forced convection film coefficients as in the tube and tube. Compactness is a plus for this design, and pressure losses satisfy design requirements. The fact that this design involves many joints gives it the disadvantage of being a difficult assembly. This problem area is being worked. The tube and shell is the prime cycle 1 design selected. A survey of the reputable names in heat exchangers manufactureres indicates that acceptable hardware from a heat transfer standpoint tend to be large, heavy, and most important, costly. This is inconsistent with our design goals of compactness and low cost.

2.3.2.10.5 <u>3-Ton and 10 Ton Economizers</u>

The 3 ton and 10 ton economizers utilize the heat of the unvaporized fluid leaving the vapor generator to preheat the fluid entering the vapor generator. In addition, the economizer cools the lubrication fluid prior to it entering the expander.

The requirements for the economizers are listed in Table 2.3-5. The approach taken in Cycle 1 was to develop and issue some general specifications to heat exchanger manufacturers. A survey of these sources provided an understanding of availability, cost, size, and performance, and resulted in the choice of a simple tube-and-tube, helically-wound heat exchanger because of its compactness and low cost.

2.3.2.10.6 Condenser (10 Ton)

Operational analysis of the 10 ton LTR cycle dictated the need for evaluation of a water cooled condenser in the 10 ton unit.

The condenser removes heat from the slightly superheated refrigerant leaving the expander, using water from a cooling tower. The refrigerant leaves the condenser as saturated liquid.

The requirements for the condenser are listed in Table 2.3-6 . The Cycle 1 approach was to generate and issue general specifications to heat exchanger manufacturers, with the result that an understanding of availability, cost, size, and performance was achieved. The choice, which is a shell and tube type condenser, represents an optimization of the above qualities.

Table 2.3-5 Economizer Requirements

Hot Side	3-TON	10-TON
Fluid	R-11 Liquid	R-11 Liquid
Temperature - Inlet (^oF)	221	222
- Outlet (^oF)	114	95
Pressure Drop	----	----
Flow Rate (lbm/hr)	155	542
Cold Side		
Fluid	R-11 Liquid	R-11 Liquid
Temperature - Inlet (^oF)	111	93
- Outlet (^oF)	127	110
Pressure - Inlet (psia)	138	139
- Outlet (psia)	137	138
Flow Rate (lbm/hr)	1112	4184

Table 2.3-6. 10-Ton Condenser Requirements

	Hot Side	
Fluid		Freon 11 with 2.48 wt. % oil
Temperature -	Inlet	128°F
	- Outlet	93°F
Pressure	- Inlet	24.7 psia
	- Outlet	20.6 psia
Flow Rate		3640 (with oil)
	Cold Side	
Fluid		Water
Temperature -	Inlet	91°F
	- Outlet	99.5°F
Pressure Drop		10 psia (approximately)
Flow Rate		78 gpm
Heat Transfer		294,152 Btu/hr (to saturated liquid)

2.3.2.10.7 Solar Driven Compressor

First cycle 3 ton and 10 ton hardware designs were released with fabrication starting in October. The first 10 ton compressor was assembled in late November with the fabrication and assembly of the remaining 3 ton and 10 ton models continuing.

A test program on the initial 10 ton compressor was initiated utilizing a 4 pole, 10 HP, 2-phase motor to simulate the expander drive. The following performance tests are planned.

1. Compressor capacity vs condition at constant RPM

2. Compressor torque vs condition at constant RPM

3. Compressor EER vs condition at constant RPM

4. Compressor capacity, torque, and EER vs speed for 45°F refrigerant

5. Compressor torque and EER vs RPM for 25°F refrigerant

6. Compressor torque and EER vs RPM for 15°F refrigerant

In addition, tests are planned utilizing a programmable AC motor (programmed to accelerate or decelerate from full speed at variable time slots 1-60 seconds) to evaluate the following:

1. Effects of slow pull up to speed on compressor bearing lubrication design reliability

2. Start up vs performance of various suction valve designs.

2.3.2.10.8 Packaging

2.3.2.10.8.1 3-Ton LTR - The packaging philosophy is still consistent with that presented last reporting period. The enclosure (see Figure 2.3-16) is a self-supporting formed sheet metal shell enclosing the LTR components and plumbing. The enclosure will be mechanically and aesthetically compatible with commercially available GE heat pump and central air conditioning units.

In this reporting period, Cycle 1 LTR components and piping/insulation requirements have been firmly identified. One major change from the past reporting period was the selection of a first cycle water cooled condenser in lieu of the previously designed air cooled model. This was done to improve prototype (deliverable units) performance as previously described.

The decision to use water cooled condensing was reached after several key LTR components originally designed for air cooled condensing refrigerant conditions, were already in the fabrication process. Performance characterization of these components will need to be accomplished by simulating air cooled condensing temperatures during test. The water cooled condenser selected will be tested at its more efficient condensing temperature range in order to assess its actual performance against that predicted analytically.

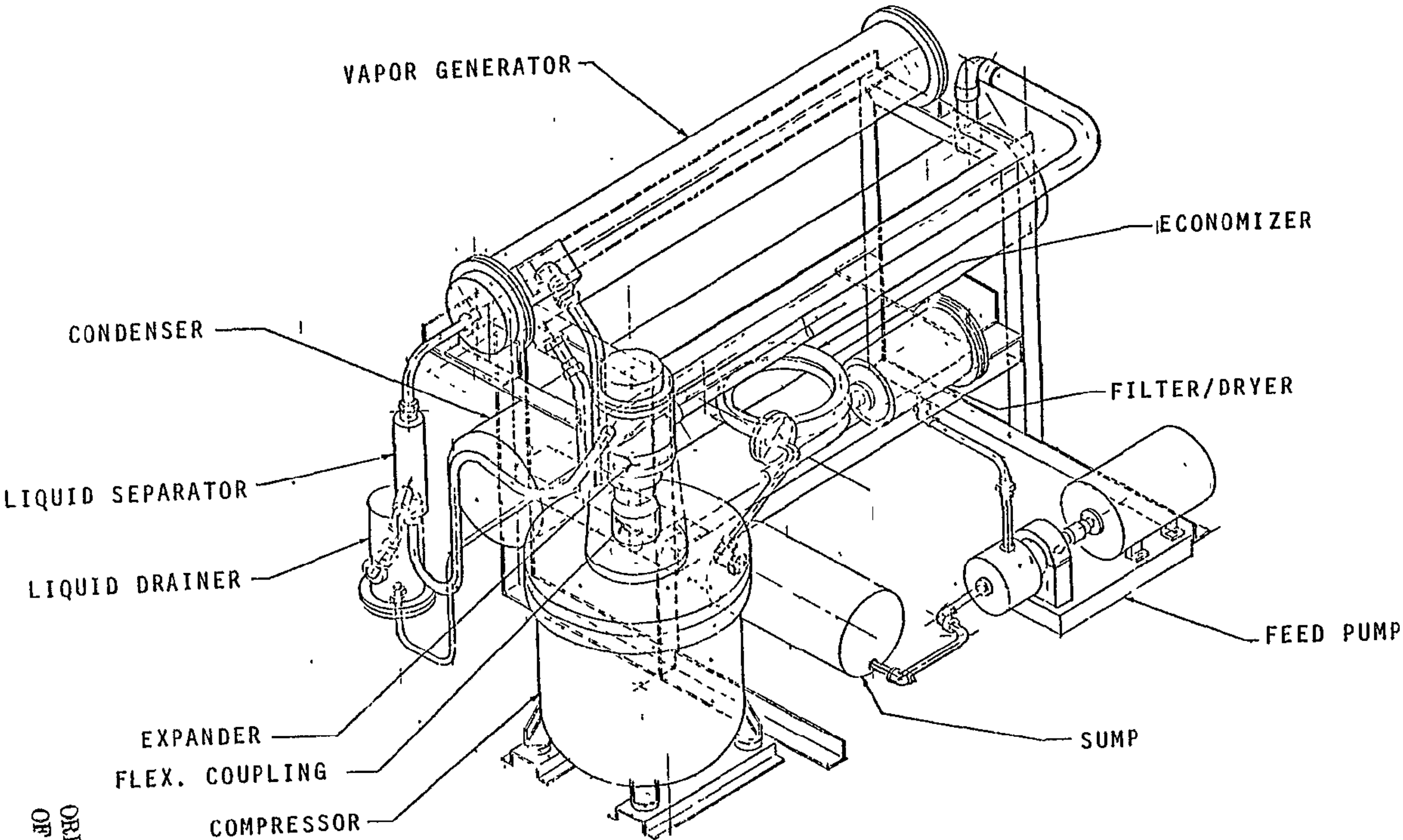


Figure 2.3-16. 3-Ton LTR Package

Figure 2.3-16. 3-Ton LTR Package

The vapor generator and condenser are supported alongside of the compressor and the expander is mounted to the compressor by a tripod steel support (see Figure 2.3-17). This structure has rabbet fits on both expander and compressor to eliminate any need for specific alignment during assembly (tolerance build up within capability of the flexible coupling).

The placement of the other LTR loop components is as shown. Copper piping will be used with brazed connections and at least one mechanical union or coupling between each component. The drawings do not show flexible piping to and from the expander which will probably be present on first cycle hardware to allow determination of vibration of the expander and compressor pairs. This will provide design information for second cycle piping.

2.3.2.10.8.2 10-Ton LTR - The 10 ton LTR loop configurations and packaging concept for first cycle is basically the same as for the 3-ton unit. The differences are in the component and piping size and in the use of a horizontal expander design. As discussed in the first Quarterly Report, the 10-ton expander was primarily used to verify scaling techniques and is, therefore, a horizontal mounted design. The current arrangement exceeds the enclosure desired for the second cycle hardware; however, it is expected that component requirements for second cycle will reduce the package size. Specifically, the separator may change to a horizontal type and component sizes in the vapor generator and condenser will be reduced. The expander is currently mounted horizontally on a separate framework which also provides the mounting for the compressor and right angle drive. This will be eliminated for the vertically mounted second cycle hardware. The structure will be similar to that used for the 3 ton unit.

NOTE: Figure included for reference only, Full size drawing supplied with document

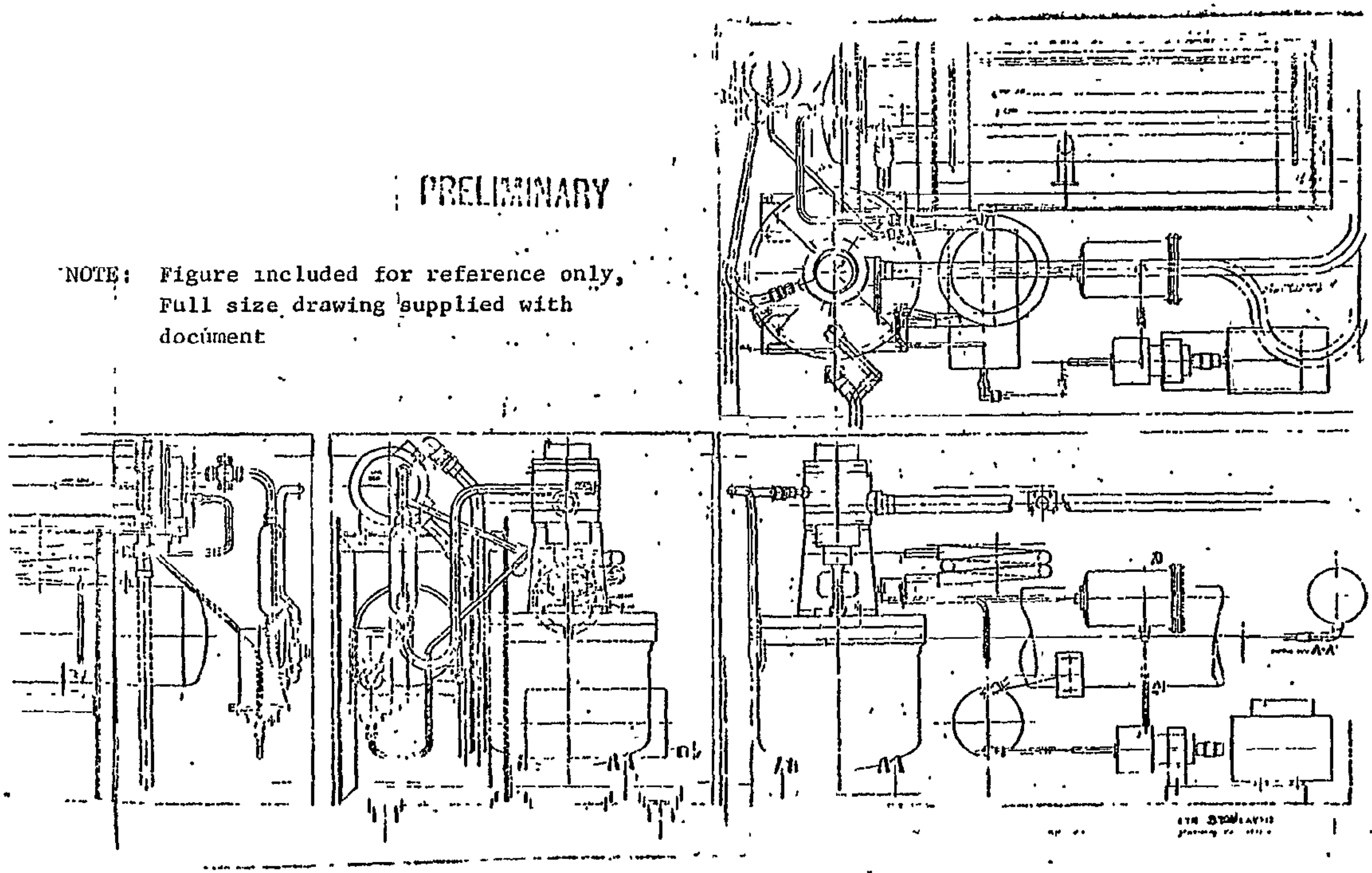


Figure 2.3-17. 3-Ton LTR Layout

2.4 TEST (WBS 1.2.3)

Test planning is proceeding at all levels of component, subsystem and system for the heating only and the heating and cooling configurations.

Test plans are completed for component development of several facets of the solar collectors (refer to paragraph 2.3.1.1).

Test facilities are essentially in place for the heating system component testing. Modification of the outdoor solar collector loop is completed and a considerable number of test runs were made using a single TC-100 collector panel (10 glass tubes) and two panels connected in series for a total of 20 glass tubes. A schematic of the modified solar collector test loop is shown in Figure 2.4-1.

Refurbishment of the existing test facilities for the Low Temperature Rankine (LTR) is proceeding on schedule. Four complete and separate test loops, two 3-ton size and two 10-ton size will be available on a full time basis to support the development testing of the LTR throughout the life of the program. Figure 2.4-2 is a typical schematic for the LTR test loop. Incorporated in the test loop design are sufficient disconnects to allow test flexibility for replacing components or substituting components as required. A by-pass loop is provided around the expander to allow testing of other LTR components (vapor generator, liquid separator, pumps, etc.) when it is convenient or desirable to do so.

The controlled environment System Test Facility for the 3-ton size (Figure 2.4-3) is in the final construction and checkout phase and is ahead of schedule to support the SHAC program.

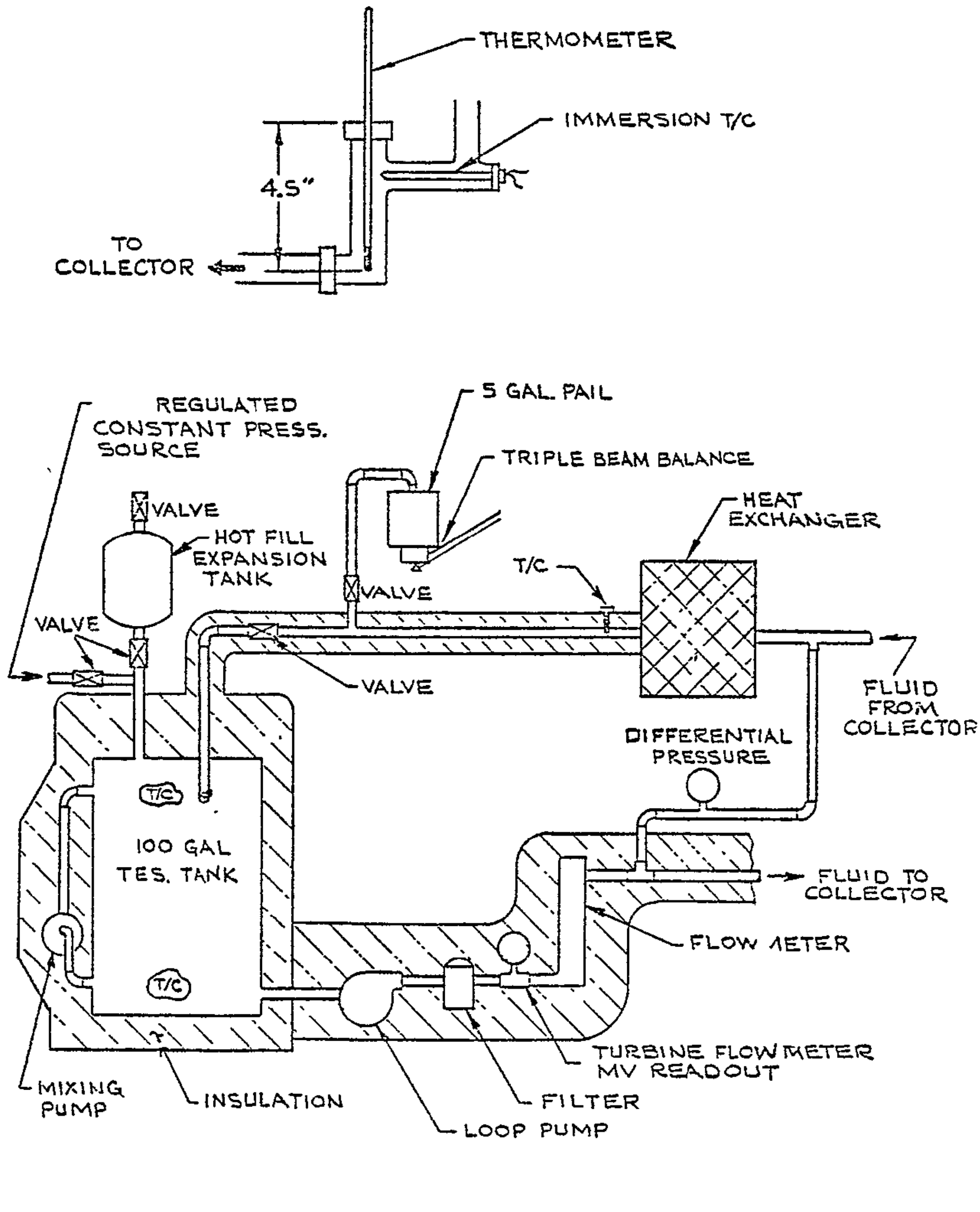


Figure 2.4-1. Solar Collector Test Facility

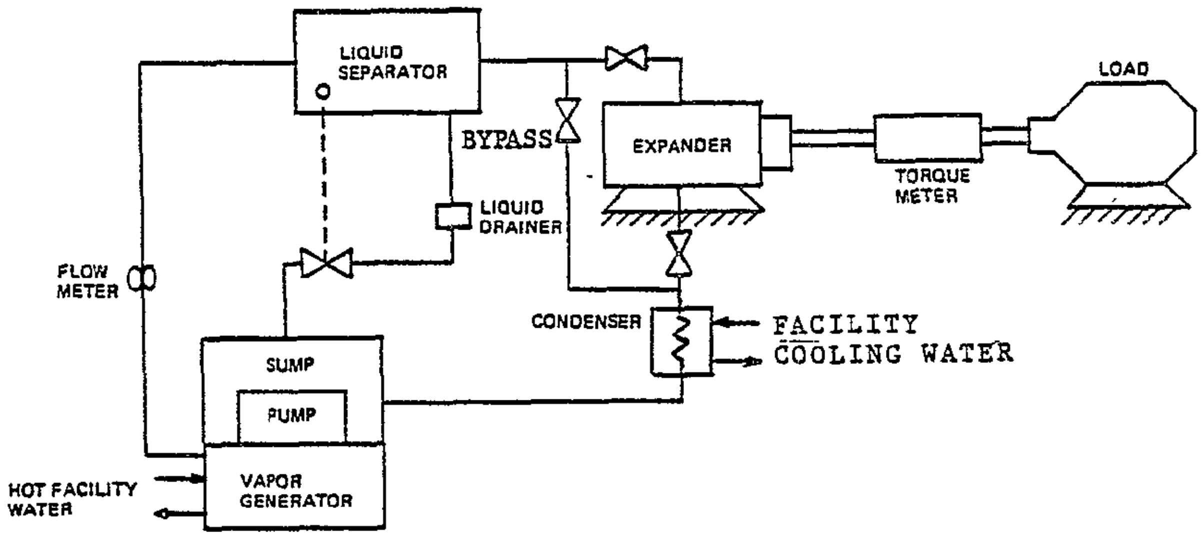


Figure 2.4-2. LTR Test Loop

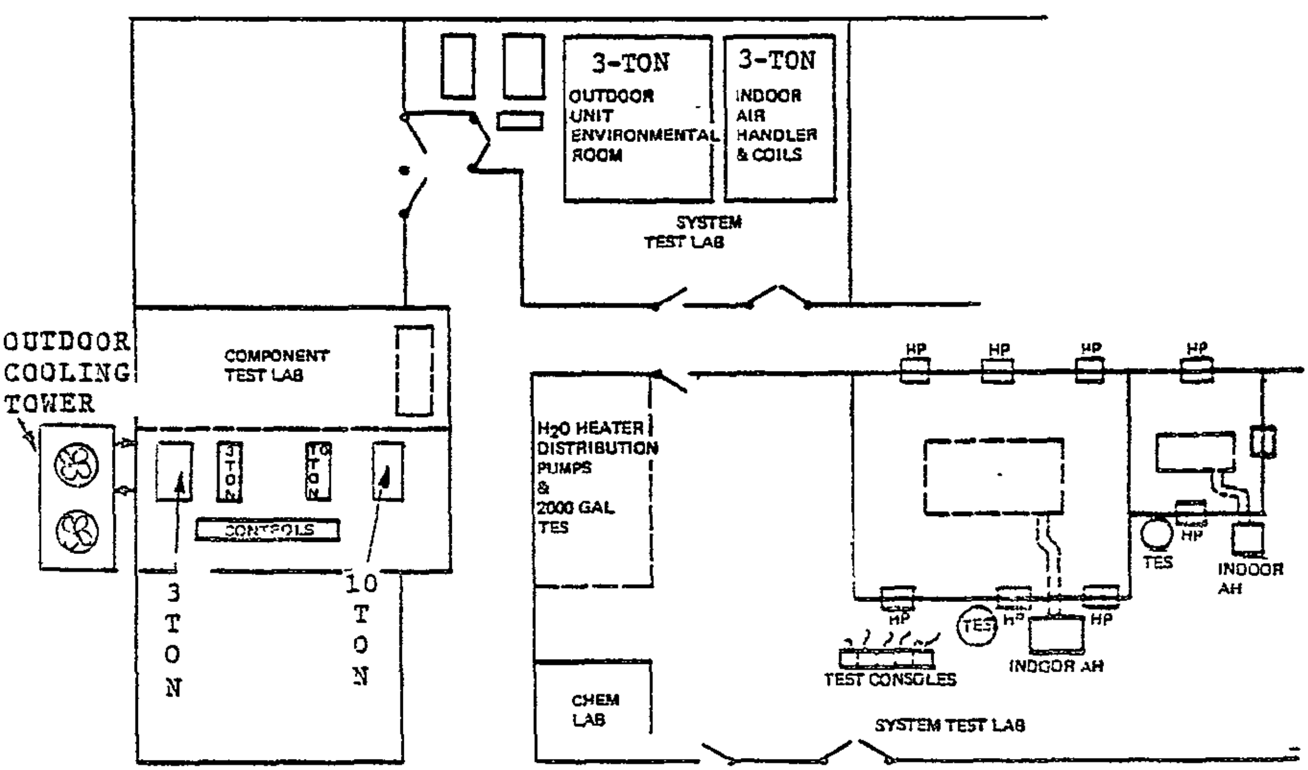


Figure 2.4-3. System Test Facility (3-Ton)

SECTION 3

DELIVERABLE HARDWARE

(Not applicable)

SECTION 4

TASK 1.4 - OPERATIONAL TEST

No significant activity for the reporting period.

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